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EVALUATION OF MARAGING STEEL FOR APPLICATION TO SPACE ~~LAUNCH VEHICLES~~

(NASA CONTRACT NAS 7-214) WOO-PR-63-172

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ABSTRACT

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Plate from a new heat of airmelted 18Ni-7Co-5Mo maraging steel has been evaluated and the results are compared to those obtained on a previously evaluated heat. Hardness, uniaxial tensile properties, and toughness were determined after selected aging treatments. The properties obtained on the new heat of material coincide reasonably well with those of the previously evaluated heat, although some differences do exist. Metallographic examination revealed the presence of inclusions and banding which may have a significant influence on properties.

Author

1. INTRODUCTION

This program is being conducted under the sponsorship of NASA, Space Vehicle Research and Technology. The purpose is to determine whether the properties of 18Ni-7Co-5Mo maraging steel and the associated processing techniques are presently applicable to space launch vehicle construction.

During the last two years, Douglas Aircraft Co. and Newport News Shipbuilding and Dry Dock Co. conducted a joint company-sponsored research and development program to evaluate 3/4-inch thick airmelted 18Ni-7Co-5Mo plate. The program was undertaken to determine the properties and fabricability of the alloy, and to define potential problem areas.

Under the current NASA contract, 3/4-inch thick plate from two new heats of airmelted 18Ni-7Co-5Mo steel will be evaluated and the results compared to those obtained in the Douglas-Newport News program.

Included in the present program are evaluations of the effects of aging treatment on uniaxial tensile properties and fracture toughness of both parent material and welds. Welds will be made in plate from one of the two new heats using the inert-gas shielded metal arc techniques and a filler wire selected during the earlier company-sponsored program. The results of the weld tests will be compared with the earlier weld data to determine whether or not these processes are reproducible and suitable for production application.

In addition, the sustained-load behavior of plate and weldments in environments normally associated with proof testing will be investigated.

This first progress report presents the results obtained on one plate from one of the two new heats to be evaluated. The results include data on uniaxial tensile properties, fracture toughness, dimensional and soundness inspection, chemical analyses, and metallographic examinations.

2. MATERIAL AND PROCEDURES

2.1 Plate

The plate evaluated in the earlier company-sponsored program shall hereafter be referred to as "Heat-1" plate (Ref. 1). This material was part of a twenty-two ton melt produced by U. S. Steel Corporation by electric furnace, air-melt techniques. Two plates, approximately 240-in. X 110-in X 3/4-in. were used in the evaluation.

Material procured for this NASA study will come from two different heats. These heats shall hereafter be referred to as "Heat-A" and "Heat-B", respectively.

Heat-A material was received as one air melted plate approximately 84-in. X 60-in. X 3/4-in. This plate was selected for evaluation because the titanium content is at the lower limit of the nominal range for the 250 ksi grade 18-7-5 alloy.

Table 1 presents the chemical compositions of Heat-1 and Heat-A plate. Douglas, Newport News, and U. S. Steel analyses are presented for Heat-A. The three agree quite closely. Heat-1 and Heat-A compositions are very similar except for the titanium content.

Heat-B material was ordered per tentative Douglas Specification DMS 1835. This specification is presented in Appendix I.

2.2 Plate Inspection Procedures

Plates from both heats were ultrasonically inspected for thickness uniformity and soundness upon receipt at Newport News. Pulse echo techniques were employed for test of soundness using standard shipyard practices. Inspection points were located on a six inch grid intersect.

2.3 Plate Layout

Figure 1 and 2 show the plate layouts use for Heat-1. Specimen numbers are indicated on the layout. Figure 3 shows the Heat-A layout. Plasma arc cutting and abrasive sawing were used to cut the rough blanks.

2.4 Test Specimen Types and Testing

Uniaxial tensile data were obtained using 0.505-inch diameter specimens illustrated in Figure 4. Fracture toughness was evaluated using the 24" X 3" X 3/4" specimen, Figure 5, with a centrally located shallow crack. The shallow crack was induced by means of flexural fatigue as described in Section 2.6. Fracture toughness evaluations conducted during the joint Douglas-Newport News program were performed with 48" X 4" X 3/4" specimens illustrated in Figure 6.

Load rates were maintained at approximately 100,000 pounds per minute for both tensile and fracture toughness testing. All tests were conducted in the ambient atmosphere at temperatures ranging from 72 to 77°F, and with dew points from 50 to 55°F.

2.5 Heat Treatment Procedures

All aging heat treatments were performed on as-machined specimens taken from the as-received, mill-annealed, plate. The mill anneal was performed at 1500°F for 1 hour followed by air cooling. All specimens were heat treated in convective air furnaces. Specimens were batch loaded into a hot furnace previously heated to the desired aging temperature. The specimens were then allowed to come to thermal equilibrium with the furnace before the nominal aging period was started.

Temperature was monitored by means of six independent thermocouples located at different positions within the furnace. The attainment of thermal equilibrium took approximately 30 to 45 minutes. Once thermal equilibrium was achieved, temperature control was maintained to within $\pm$ 5°F.

The majority of the 0.505-inch diameter tensile specimens were furnace loaded in four bundles of four specimens each (two transverse and two longitudinal) at each of the four aging temperatures employed. Monitoring thermocouples were attached to each bundle. Four-specimen bundles were removed, successively, after each of four aging periods and subsequently air cooled in ambient still air to room temperature.

Six 0.505-inch diameter specimens used to check the tensile properties of the Heat-A plate were heat treated in one load at 900°F for 3 hours. The six 24" X 3" X 3/4" fracture toughness specimens were also heat treated in a single load at 900°F for 3 hours.

2.6 Preparation of Shallow-Crack Specimens

Shallow cracks were induced in the fracture toughness specimens by means of a flexural fatigue procedure similar to that described in Douglas Laboratory Procedure, DLP 13.822 presented in Appendix II. The DLP presents the procedure used for sheet material, rather than plate. However, the general procedures are identical for sheet and plate.

Approximately 5,000 cycles were required to initiate a visible crack, and up to 15,000 cycles (at 110 cycles per minute) were needed to achieve the desired crack size.

3. RESULTS AND DISCUSSION

3.1 Dimensional, Soundness and Hardness Inspection

Ultrasonic inspection failed to indicate any defects, rejectable per DMS 1835, in either Heat-1 or A plates.

Thickness traverse data are tabulated in Tables II thru IV. The tolerances for Heat-1 plates exceed the maximum specified in AMS 2252 (plus 0.044, minus 0.010-in.) ranging between 0.750-in. plus 0.059, minus zero for plate 1 and plus 0.088, minus zero for plate 2. Heat-A plate thickness ranges between 0.750 plus 0.044, minus zero. The latter boarders on the upper limit of AMS 2252 requirements.

Plate surfaces are characterized by a rather tenacious mill scale which is not readily removed by grit blasting. The thickness of the scale is approximately 0.001 inches and does not appear to be damaging.

The hardness of the as-received plate averaged 34 Rockwell C, and ranged from 32 to 34.5 Rockwell C. These values are at the limit specified in DMS 1835.

3.2 Metallographic Examination

Metallographic specimens were examined from Heat-A plate in the as-received mill-annealed condition. Both transverse and longitudinal sections were examined. Figure 7 illustrates characteristic microstructures. Figure 7-a represents the general appearance for both longitudinal and transverse specimens. Banding is prevalent and is more pronounced on transverse than on longitudinal sections. Similar microstructures were observed for Heat-1 plate.

Figure 7-b illustrates a type of inclusion found very occasionally. This type of inclusion appears predominately within light etching bands. The extremities of the inclusions appear to be bounded by sharp cornered voids. The voids may have been produced by selective etching; however, in all probability they were induced during plate rolling when the inclusions failed to deform and elongate into the surrounding material. Positive identification of this type of inclusion

is not available, however, other investigators have suggested the possibility of a complex titanium-carbon-nitrogen intermetallic phase. The effects that these inclusions may have on properties are not presently known.

3.3 Tensile Property Check

Six 0.505 tensile specimens, aged at 900°F for 3 hours, were tensile tested to determine whether or not Heat-A plate possessed the minimum property requirements specified in DMS 1835. Table V presents the data. The properties exceed the minimum requirements of the specification.

3.4 Effect of Rolling Direction and Aging Treatment on Tensile Properties

Figures 8 thru 12 show the effect of aging time and temperature on the uniaxial tensile properties of both transverse and longitudinal 0.505-in. diameter specimens from the Heat-A plate. Data shown are for aging temperatures of 875,900 and 950°F and aging times of 1, 3, 6, and 12 hours. Each point represents an individual test specimen.

Data for Heat-1 are shown in Figure 11. Specimens were aged for times of 1, 3, 8, or 15 hours. Yield stress data are not illustrated in Figure 11 since values for the range were not obtained. Tabulated data for both Heat-1 and Heat-A are presented in Appendix III. Heats-1 and A are compared in Figure 12.

The data may be summarized as follows:

1. The tensile properties of Heat-1 plate are essentially constant after aging at 900 to 950°F (Figure 11) for 3 to 8 hours. Aging at 900 and 925°F for 15 hours produces very little changes compared to shorter aging times at the same temperatures.

2. Heat-1 plate aged at 875°F (Figure 11) exhibits increasing tensile strength with increasing aging time. After

3 hours at 875°F the strength is significantly lower than that achieved upon aging at 900 to 950°F. However, from 8 to 15 hours the strength levels are about equal after aging from 875 to 950°F. Ductility remains virtually constant for all conditions.

3. Aging of Heat-1 plate at 1000°F (Figure 11) produces continuous degradation of strength between 1 and 8 hours exposure. At the same time, ductility tends to increase slightly. The tensile properties after aging from 1 to 3 hours at 1000°F are about the same as those achieved by 3 hour aging at 875°F. After 3 hours, however the strengths obtained after 875°F and 1000°F aging diverge considerably.

4. Heat-A plate aged at 875°F (Figure 8) and 900°F (Figure 9) from 1 to 12 hours exhibit nearly the same tensile properties. However at 875°F tensile strength appears to be increasing after 12 hours while at 900°F a plateau seems to have been reached. Transverse properties tend to be somewhat inferior to longitudinal, however, the differences are rather small.

5. Heat-A plate aged at 950°F (Figure 10) attains peak strength after a 3 hour aging treatment. Thereafter, strength decreases gradually with increasing time. This behavior is typical of a precipitation hardenable alloy system. Ductility is not decisively affected by the aging treatment. The strength achieved at 950°F is considerably lower than that attained by aging at 875 or 900°F. The strength of transverse specimens is about equal to or slightly better than longitudinal specimens; however, the ductility of transverse specimens is somewhat poorer than longitudinal specimens.

6. Figure 12 permits a direct comparison of Heat-1 and A. Although no startling differences exist, the differences that do prevail are striking in view of the very similar

chemical compositions. Heat-A plate appears to respond to an 875°F aging treatment quicker than Heat-1 but both reach about the same strength level after prolonged aging. Within the range investigated, properties after 900°F aging are quite similar. The greatest apparent difference persists after 950°F aging. Heat-A exhibits consistently lower strength, but even more significantly pronounced overaging characterizes this heat. Heat-1 exhibits no tendency towards overaging within the time range evaluated (3 to 8 hours). Since titanium is the principal compositional difference, the latter observation suggests the possibility that titanium may impart resistance to overaging.

3.5 Effects of Aging Treatment on Hardness

The dependence of hardness on the aging treatment is depicted graphically in Figures 13 and 14 for both heats. Each point represents the average of four to eight identations. As may be seen, hardness remains very nearly constant over a wide range of aging times and temperatures. Consequently, hardness cannot be correlated closely to tensile properties.

Heat-1 plate is somewhat harder than Heat-A, especially after 950°F aging treatments. This difference coincides with the tensile property differences observed after the 950°F treatment. However, it is doubtful that such hardness disparities could be used to predict tensile property differences, especially where compositional differences are greater than those which prevail between Heat-1 and A material.

3.6 Net-Fracture Stress

Figure 15 describes the dependence of net-fracture stress (failing load divided by the net section area, i.e., gage area less crack area) on shallow-crack depth for Heats-1 and A plate. The specimens were aged for 3 hours at 900°F. Heat-1 data are for longitudinal specimens only, while both transverse and longitudinal data are presented for Heat-A. Crack depth, rather than another crack shape parameter, was selected as the independent variable. However, it should be recognized that depth alone may not be the most significant crack shape parameter. Additional comments on this point will be made in future progress reports. Data on crack length, depth, and gross fracture stress are presented in Tables VI and VII.

The results depicted in Figure 15 show that the net-fracture stress of Heat-1 plate remains constant until a crack depth of approximately 0.110 inches is reached. Thereafter, the net-fracture stress decreases steadily with increasing crack depth. Heat-A data exhibit very close agreement with that for Heat-1. The longitudinal properties of Heat-A may be slightly superior to those for Heat-1, but the differences are quite small. The transverse properties of Heat-A plate appear to be somewhat inferior to the longitudinal properties. This may be ascertained by comparing the net-fracture stresses for approximately identical crack sizes.

3.7 Plain Strain Fracture Toughness

Plain strain fracture toughness values, K_{IC}, are presented in Tables VI and VII for both heats. The values were calculated from Irwin's equation (Ref. 2), as follows:

$$K_{IC} = \sqrt{\frac{3.77\sigma^2 b}{\phi^2 - 0.212\left(\frac{\sigma}{\sigma_{Y.S.}}\right)^2}}$$

where

$$\phi = \int_{\theta=0}^{\theta=\pi/2} \sqrt{1-\left(\frac{a^2-b^2}{a^2}\right)\sin^2\theta}\, d\theta$$

$2a$ = Crack length
b = Crack depth
σ = Gross-fracture stress
$\sigma_{Y.S.}$ = 0.2% offset yield strength

Values of K_{IC} for plate from both heats fall within the range of 100 to 125 ksi$\sqrt{in.}$, with no decisive differences apparent between heats. Longitudinal and transverse specimens from Heat-A possess about the same K_{IC} values, although the lowest K_{IC} was obtained for a transverse specimen.

3.8 Fracture Surfaces

Figure 16 illustrates fracture surfaces typical of transverse and longitudinal shallow-crack specimens from Heat-A plate, The transverse specimens exhibit surfaces characterized by striations parallel to the rolling direction. Striations are far less prevalent on the fracture surfaces of the longitudinal specimens. The striations are probably related to the banded microstructure illustrated in Figure 7. Work is presently underway to further examine the nature of the fracture surface striations.

4. SUMMARY AND CONCLUSIONS

In summary the following conclusions may be made:

1. Ultrasonic inspection of Heat-1 and A plate indicated acceptable soundness. However, metallographic examination reveals the presence of inclusions which may be potentially damaging.

2. The effects of aging treatment on uniaxial tensile properties are similar for both heats. However, Heat-1 appears to somewhat more resistant to overaging than Heat-A. This behavior might be related to the difference in titanium contents.

3. The tensile properties in the longitudinal and transverse directions are very similar, but ductility in the transverse direction is generally inferior to longitudinal.

4. Hardness is not appreciably affected by aging treatments

of 1 to 12 hour duration conducted at temperatures from 875°F to 950°F. No definitive relationship exists between hardness and tensile properties.

5. Net-fracture stress properties of Heat-1 and A plate are quite similar. However, transverse specimens from Heat-A exhibit somewhat lower net-fracture stress values for a given crack size than do longitudinal specimens. Also fracture surface appearances are different for the two orientations. These differences may possibly be related to the banded microstructure which tends to prevail in this alloy.

6. Plain strain fracture toughness values, K_{IC} , are virtually equal for Heat-1 and A plate ranging between 100 and 125 ksi $\sqrt{in}$. No conclusive dependence on specimen orientation was found from the limited data; however, transverse properties may be somewhat inferior to longitudinal properties.

5. FUTURE WORK

Heat-B plate and welding wire are on order. Upon receipt of the material, the comprehensive evaluations of Heat-B will begin in accordance with the proposed program.

6. REFERENCES

1. "Proposal to Evaluate Air-Melted 18Ni-7Co-5Mo Maraging Steel for Application to Space Launch Vehicle Structures" Douglas Report SM-42460, Oct. 1962.

2. Irwin, G. R. "Fracture Testing of High Strength Materials Under Conditions Appropriate for Stress Analysis". Naval Research Laboratory Report No. 5486, July 27, 1960.

3. Douglas Data Book PCR No. 20009

TABLE 1

CHEMICAL COMPOSITIONS OF 3/4-INCH THICK
AIRMELTED 18Ni-7Co-5Mo PLATE

HEAT CODE	U.S.S. HEAT NO.	CHEMICAL COMPOSITION, WT. PERCENT														SOURCE
		C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Al	Ti	Co	B	Zr	
1	X13371	0.02	0.04	0.004	0.009	0.08	0.05	17.83	0.01	4.70	0.11	0.46	7.41	NA	NA	U.S.S.
A	X14359	0.02	0.03	0.005	0.005	0.09	0.11	17.73	0.01	4.80	0.07	0.39	7.40	0.004	0.01	U.S.S.
A	X14359	0.01	0.06	0.002	0.006	0.07	NA	17.35	NA	4.79	NA	0.41	7.81	NA	0.01	Douglas
A	X14359	0.02	0.06	0.009	0.004	0.08	0.05	17.83	NA	4.68	0.15	0.39	6.98	0.00039	0.0022	Newport News

NA - NO ANALYSIS

TABLE II

ULTRASONIC THICKNESS TRAVERSE FOR HEAT-1, PLATE 1

108"

6"

6"

240"

.765	.768	.775	.770	.775	.778	.780	.780	.785	.785	.785	.785	.773	.775	.777	.770	.780	.780	.776
.775	.773	.775	.780	.783	.780	.780	.780	.790	.787	.785	.786	.780	.783	.778	.775	.780	.780	.770
.768	.775	.780	.778	.783	.783	.783	.783	.790	.793	.787	.785	.785	.786	.780	.775	.782	.785	.775
.768	.773	.783	.780	.780	.780	.783	.783	.787	.787	.790	.786	.783	.782	.780	.777	.786	.783	.767
.765	.770	.770	.775	.778	.785	.780	.783	.790	.787	.787	.787	.785	.785	.780	.777	.783	.780	.765
.768	.775	.778	.780	.783	.783	.785	.785	.790	.793	.792	.788	.787	.786	.785	.780	.783	.782	.775
.770	.770	.780	.783	.783	.783	.788	.785	.793	.794	.790	.792	.767	.785	.783	.783	.784	.783	.770
.770	.775	.775	.780	.780	.780	.783	.783	.790	.793	.790	.794	.790	.785	.785	.780	.785	.783	.773
.775	.770	.775	.780	.783	.785	.783	.788	.783	.786	.792	.786	.784	.795	.792	.788	.787	.784	.774
.780	.780	.788	.790	.793	.793	.800	.800	.796	.790	.795	.793	.792	.800	.795	.790	.786	.784	.771
.778	.780	.785	.785	.790	.793	.795	.800	.792	.789	.790	.786	.788	.797	.790	.787	.787	.787	.770
.775	.783	.780	.785	.790	.790	.795	.795	.790	.787	.792	.788	.786	.795	.793	.792	.785	.782	.770
.775	.780	.783	.785	.788	.795	.795	.798	.800	.805	.798	.802	.800	.797	.795	.793	.786	.783	.773
.775	.780	.783	.783	.785	.788	.790	.790	.809	.806	.800	.804	.805	.798	.797	.793	.788	.785	.772
.773	.778	.778	.780	.788	.790	.790	.790	.807	.806	.804	.807	.803	.798	.797	.795	.787	.785	.775
.775	.780	.783	.788	.788	.793	.795	.793	.806	.808	.807	.805	.803	.800	.797	.795	.787	.787	.775
.773	.780	.780	.783	.785	.788	.793	.790	.805	.803	.800	.800	.803	.798	.793	.793	.795	.788	.780
.772	.775	.780	.784	.790	.788	.793	.794	.803	.802	.805	.804	.802	.797	.795	.790	.788	.786	.776
.767	.775	.780	.784	.787	.790	.791	.795	.800	.803	.800	.804	.800	.800	.793	.790	.787	.786	.775
.766	.775	.782	.786	.786	.791	.790	.793	.800	.800	.803	.803	.800	.800	.800	.790	.787	.784	.772
.768	.778	.780	.783	.785	.788	.794	.791	.805	.805	.803	.803	.803	.800	.797	.792	.786	.778	.763
.766	.780	.780	.785	.767	.767	.790	.792	.805	.805	.803	.805	.803	.800	.796	.793	.785	.782	.766
.766	.777	.773	.784	.785	.786	.792	.792	.803	.805	.803	.802	.800	.800	.795	.795	.782	.782	.774
.783	.787	.790	.793	.795	.793	.793	.800	.795	.796	.800	.797	.792	.788	.786	.785	.780	.780	.770
.780	.788	.793	.795	.780	.793	.795	.793	.800	.800	.795	.795	.798	.787	.791	.785	.783	.780	.770
.780	.788	.786	.792	.793	.790	.794	.793	.793	.793	.797	.780	.790	.785	.790	.782	.775	.775	.760
.780	.785	.790	.793	.800	.793	.795	.795	.800	.796	.795	.794	.795	.792	.788	.783	.785	.780	.770
.777	.785	.791	.790	.793	.793	.791	.800	.795	.805	.800	.787	.794	.785	.782	.787	.787	.786	.775
.785	.790	.793	.795	.795	.795	.797	.797	.800	.800	.795	.787	.785	.790	.790	.783	.780	.783	.770
.785	.790	.793	.794	.797	.795	.796	.795	.800	.795	.798	.791	.790	.787	.786	.785	.783	.780	.765
.785	.787	.793	.793	.793	.795	.797	.796	.792	.800	.794	.792	.795	.793	.785	.786	.785	.780	.770
.784	.793	.798	.795	.795	.799	.795	.797	.790	.795	.797	.791	.793	.790	.785	.785	.785	.782	.775
.785	.793	.798	.795	.795	.795	.795	.805	.789	.795	.792	.790	.793	.790	.784	.783	.780	.780	.765
.780	.783	.790	.795	.797	.803	.805	.805	.800	.795	.800	.793	.800	.798	.803	.793	.785	.780	.775
.780	.790	.790	.793	.795	.795	.797	.798	.802	.804	.795	.795	.795	.793	.792	.788	.780	.775	.770
.780	.785	.787	.790	.793	.793	.793	.795	.796	.799	.794	.794	.794	.792	.792	.786	.777	.775	.770
.782	.787	.790	.793	.795	.797	.798	.798	.796	.798	.798	.792	.793	.789	.791	.790	.780	.775	.780
.783	.790	.790	.793	.795	.793	.798	.800	.797	.793	.800	.796	.797	.793	.795	.790	.782	.780	.780
.780	.787	.790	.797	.795	.800	.800	.800	.804	.795	.795	.797	.792	.788	.795	.796	.780	.780	.775
.765	.777	.780	.787	.792	.800	.800	.800	.795	.795	.790	.790	.782	.780	.790	.790	.786		

TABLE III
ULTRASONIC THICKNESS TRAVERSE FOR HEAT 1 – PLATE 2

ULTRASONIC THICKNESS TRAVERSE FOR HEAT 1 – PLATE 2

6" 6" 240"

.795	.800	.803	.805	.805	.805	.805	.805	.805	.805	.805	.803	.803	.800	.798	.790	.803	.795	.780
.795	.800	.805	.805	.808	.810	.810	.810	.810	.810	.810	.805	.805	.803	.800	.793	.805	.795	.785
.795	.803	.810	.810	.813	.815	.815	.815	.805	.805	.805	.803	.798	.795	.800	.800	.808	.800	.788
.803	.808	.810	.813	.813	.815	.815	.185	.808	.818	.818	.815	.815	.810	.810	.808	.813	.805	.790
.803	.810	.808	.818	.818	.818	.818	.818	.825	.825	.825	.818	.815	.813	.810	.803	.815	.803	.793
.803	.805	.810	.815	.818	.818	.820	.820	.825	.825	.825	.823	.818	.815	.815	.810	.815	.805	.795
.805	.808	.810	.818	.818	.818	.820	.820	.825	.825	.825	.825	.820	.815	.818	.808	.815	.805	.800
.800	.803	.805	.813	.818	.820	.825	.820	.825	.825	.825	.823	.818	.815	.818	.810	.815	.810	.795
.803	.788	.813	.818	.818	.818	.820	.820	.830	.830	.825	.825	.820	.815	.813	.805	.818	.805	.793
.803	.805	.810	.813	.818	.818	.818	.818	.825	.825	.825	.823	.820	.820	.813	.808	.818	.805	.795
.803	.813	.815	.813	.825	.823	.823	.820	.830	.825	.823	.820	.825	.820	.815	.813	.818	.808	.795
.803	.808	.810	.820	.820	.823	.825	.823	.830	.830	.830	.825	.823	.820	.813	.813	.818	.810	.800
.808	.810	.815	.818	.820	.823	.823	.823	.835	.833	.830	.833	.823	.820	.815	.810	.818	.810	.795
.805	.808	.813	.820	.818	.820	.823	.823	.828	.825	.825	.828	.823	.818	.815	.810	.815	.805	.795
.805	.810	.813	.818	.820	.828	.825	.828	.833	.835	.830	.830	.825	.820	.815	.815	.820	.810	.803
.805	.813	.815	.825	.825	.828	.830	.833	.838	.838	.838	.833	.828	.828	.823	.815	.823	.813	.803
.805	.810	.818	.820	.823	.823	.825	.825	.833	.835	.835	.833	.828	.825	.815	.813	.820	.810	.803
.803	.808	.810	.820	.818	.825	.825	.825	.830	.830	.825	.828	.825	.825	.820	.810	.820	.810	.800
.808	.810	.815	.825	.823	.828	.815	.830	.835	.838	.833	.833	.828	.823	.823	.815	.825	.810	.800
.808	.813	.820	.823	.825	.825	.835	.828	.835	.838	.835	.835	.830	.823	.820	.818	.823	.818	.803
.810	.815	.815	.820	.825	.828	.828	.828	.833	.835	.833	.830	.825	.828	.820	.815	.820	.815	.805
.805	.805	.810	.815	.818	.820	.820	.823	.830	.828	.825	.825	.820	.818	.818	.810	.820	.810	.795
.798	.803	.805	.806	.808	.813	.813	.813	.818	.818	.818	.815	.810	.810	.805	.805	.813	.800	.788
.795	.800	.800	.808	.808	.810	.810	.810	.818	.818	.818	.815	.813	.808	.805	.803	.810	.800	.785
.793	.798	.803	.805	.805	.810	.805	.808	.810	.815	.813	.810	.808	.805	.803	.800	.803	.795	.780
.790	.793	.798	.800	.803	.803	.803	.803	.805	.808	.810	.810	.808	.803	.800	.795	.803	.793	.780
.788	.790	.790	.798	.798	.803	.800	.800	.805	.805	.808	.808	.805	.803	.800	.798	.800	.790	.775
.785	.790	.793	.795	.795	.798	.800	.800	.800	.803	.805	.795	.800	.795	.795	.790	.798	.788	.778
.785	.790	.790	.793	.795	.795	.795	.798	.810	.800	.800	.800	.795	.793	.790	.790	.795	.788	.775
.783	.788	.790	.793	.795	.795	.795	.795	.795	.795	.793	.795	.793	.790	.788	.785	.793	.785	.775
.783	.788	.790	.793	.795	.793	.793	.793	.793	.795	.790	.790	.788	.788	.783	.785	.790	.785	.770
.783	.788	.790	.790	.790	.793	.790	.793	.790	.790	.788	.788	.775	.783	.783	.780	.790	.783	.773
.778	.780	.780	.783	.785	.785	.785	.785	.783	.785	.783	.780	.778	.778	.775	.773	.785	.773	.765
.775	.780	.780	.780	.780	.780	.780	.780	.780	.778	.778	.780	.770	.773	.770	.770	.780	.773	.768
.780	.780	.783	.785	.785	.785	.785	.785	.783	.785	.785	.783	.780	.778	.778	.775	.785	.778	.768
.788	.790	.793	.795	.795	.795	.795	.795	.808	.795	.795	.790	.790	.788	.785	.785	.795	.790	.775
.798	.800	.808	.808	.808	.813	.810	.808	.805	.810	.805	.803	.795	.793	.800	.790	.805	.795	.783

TABLE IV

ULTRASONIC THICKNESS TRAVERSE FOR HEAT-A PLATE

6" (column spacing); 6" (row spacing); 84" (plate width); 60" (plate length)

.782	.780	.765	.776	.775	.780	.782	.782	.780
.780	.782	.780	.783	.782	.786	.784	.782	.782
.785	.788	.785	.784	.784	.786	.786	.784	.784
.788	.785	.785	.782	.784	.786	.788	.786	.790
.786	.789	.785	.786	.786	.790	.790	.788	.788
.788	.794	.789	.788	.784	.782	.786	.790	.788
.790	.790	.786	.786	.780	.786	.790	.790	.792
.790	.792	.788	.786	.788	.788	.788	.790	.790
.792	.790	.790	.786	.788	.790	.788	.788	.788
.790	.790	.788	.788	.786	.788	.790	.786	.786
.788	.790	.790	.790	.788	.788	.786	.786	.786
.790	.790	.786	.786	.786	.786	.786	.784	.784
.788	.785	.784	.786	.784	.782	.784	.782	.784

TABLE V

HEAT-A PLATE TENSILE DATA

SPEC. NO	SPECIMEN ORIENTATION	0.2% YIELD STRESS, ksi	ULTIMATE STRESS, ksi	% ELONG. (2 in. GAGE)	%RED. IN AREA
AP 31	L	253.0	259.0	11.0	45.5
AP 32	L	252.0	258.5	11.0	44.9
AP 33	L	253.6	258.8	11.0	44.0
AP 34	T	255.0	260.8	8.0	32.5
AP 35	T	252.0	260.0	10.0	36.6
AP 36	T	254.0	260.3	9.0	38.8

NOTES:

1. L=Longitudinal

   T=Transverse

2. All results obtained with 0.505-in. diameter specimens.

TABLE VI

PLANE STRAIN FRACTURE TOUGHNESS VALUES-
HEAT-1 PLATE

SPEC. NO.	CRACK LENGTH, In.	CRACK DEPTH, In.	GROSS FRACTURE STRESS, KSI	K_{IC}, KSI $\sqrt{In.}$
1-13	None	None	265.8	--
1-11	0.125	0.062	264.8	--
1-18	0.240	0.110	260.3	--
1-9	0.300	0.120	247.2	123.3
1-8	0.380	0.150	206.6	114.0
1-2	0.435	0.165	202.6	116.6
1-12	0.490	0.180	183.1	113.2
1-7	0.560	0.190	168.1	109.6
1-10	0.606	0.205	155.2	104.9
1-17	0.730	0.240	147.9	109.0
1-14	1.000	0.290	119.4	100.2

Notes:

1) All results obtained with 48" x 4" x 3/4 specimens.
2) All specimens are longitudinal.
3) Specimens aged 3 hrs. at 900°F. 0.2% yield strength = 260.0 KSI.
4) Blank in K_{IC} column indicates non applicable value.
5) Gross fracture stress = failing load divided by uncracked gage area.

TABLE VII

PLANE STRAIN FRACTURE TOUGHNESS VALUES-
HEAT-A PLATE

SPEC. NO.	ORIENTATION	CRACK LENGTH, In.	CRACK DEPTH, In.	GROSS FRACTURE STRESS, KSI	K_{IC} KSI $\sqrt{\text{In.}}$
AP4-1	L	0.224	0.104	263.3	--
AP4-2	L	0.296	0.131	251.5	125.3
AP4-3	L	0.383	0.173	200.1	111.2
AP4-4	T	0.246	0.111	243.8	110.3
AP4-5	T	0.306	0.130	225.1	112.9
AP4-6	T	0.377	0.152	180.8	98.7

Notes:

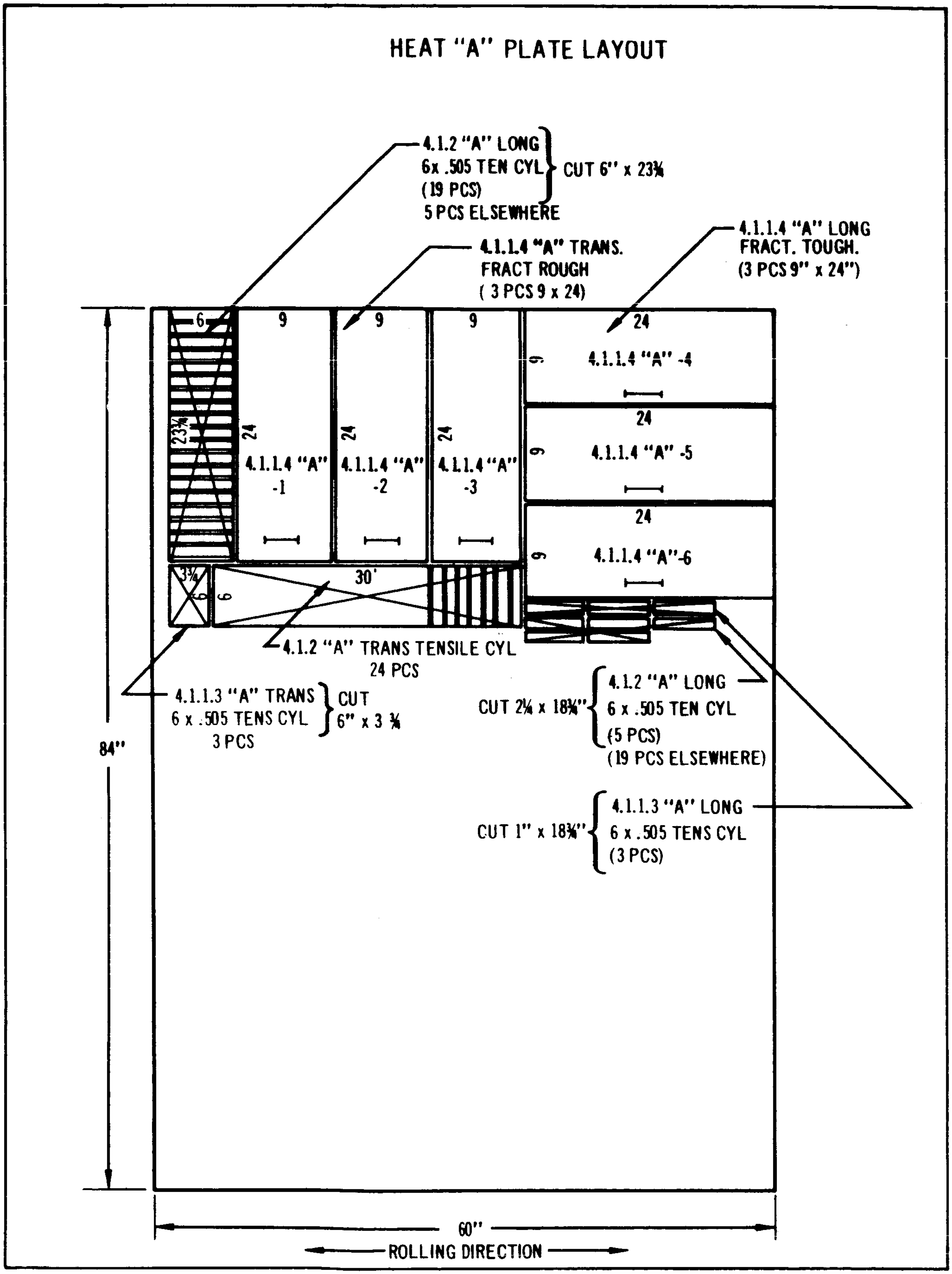
1) All results obtained with 24" x 3" x 3/4" specimens

2) L = Longitudinal; T = Transverse

3) Specimens aged 3 hrs. at 900°F. 0.2% yield strength = 254.8 KSI

4) Blank in K_{IC} column indicates non applicable value

5) Gross fracture stress = failing load divided by uncracked gage area



HEAT "A" PLATE LAYOUT
4.1.2 "A" LONG
6x .505 TEN CYL
(19 PCS)
CUT 6" x 23¾
5 PCS ELSEWHERE
4.1.1.4 "A" TRANS.
FRACT ROUGH
(3 PCS 9 x 24)
4.1.1.4 "A" LONG
FRACT. TOUGH.
(3 PCS 9" x 24")
6
9
9
9
24
23¾
24
4.1.1.4 "A"
-1
4.1.1.4 "A"
-2
4.1.1.4 "A"
-3
4.1.1.4 "A" -4
4.1.1.4 "A" -5
4.1.1.4 "A"-6
3¾
30'
4.1.2 "A" TRANS TENSILE CYL
24 PCS
4.1.1.3 "A" TRANS
6 x .505 TENS CYL
3 PCS
CUT
6" x 3 ¾
CUT 2¼ x 18¾"
4.1.2 "A" LONG
6 x .505 TEN CYL
(5 PCS)
(19 PCS ELSEWHERE)
CUT 1" x 18¾"
4.1.1.3 "A" LONG
6 x .505 TENS CYL
(3 PCS)
84"
60"
ROLLING DIRECTION

FIGURE 3

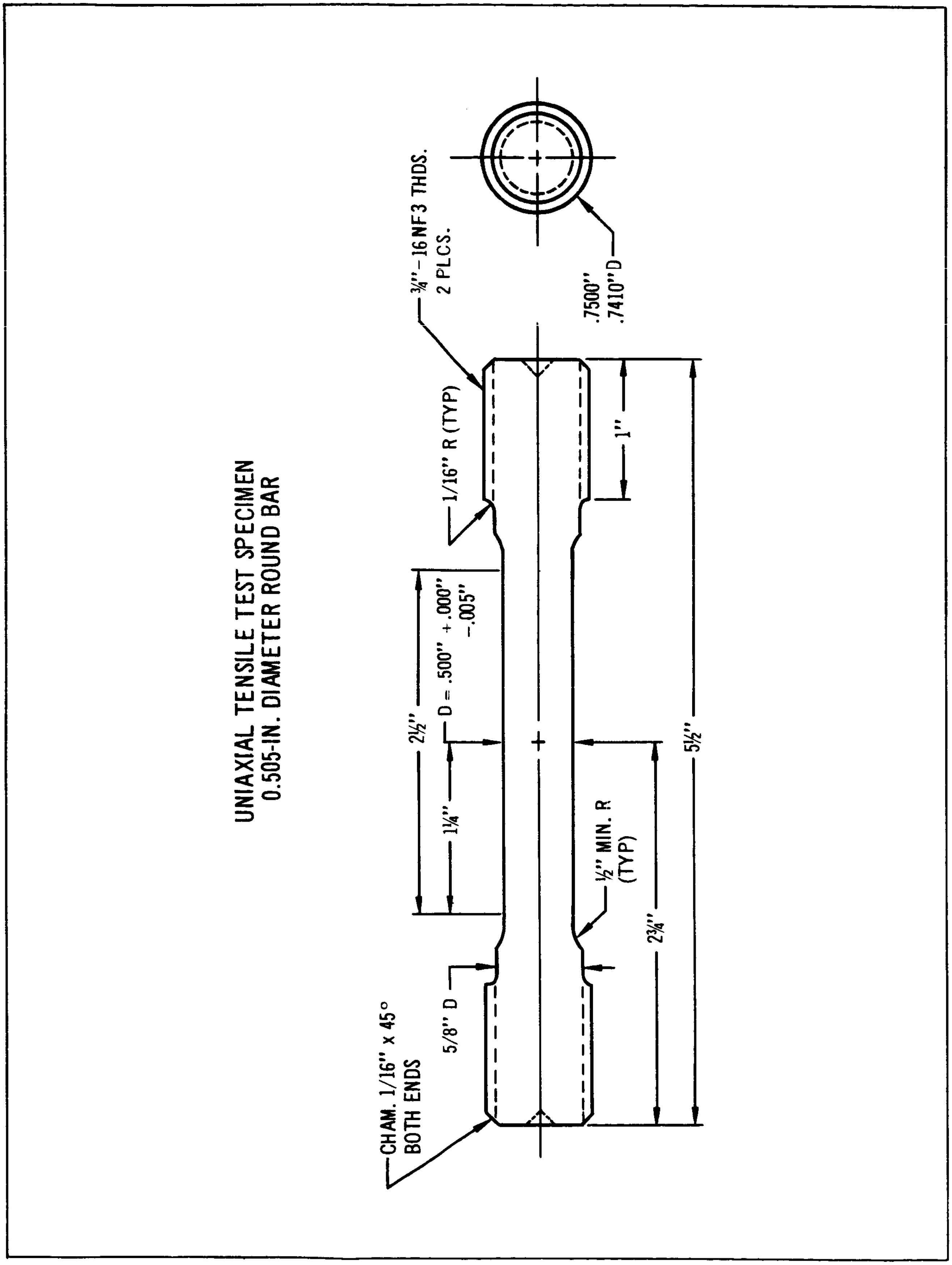

UNIAXIAL TENSILE TEST SPECIMEN
0.505-IN. DIAMETER ROUND BAR
¾"-16 NF3 THDS.
2 PLCS.
.7500"
.7410" D
1/16" R (TYP)
1"
D = .500" +.000"
-.005"
2½"
1¼"
½" MIN. R
(TYP)
2¾"
5½"
5/8" D
CHAM. 1/16" x 45°
BOTH ENDS

FIGURE 4

LAYOUT, HEAT-I, PLATE NO. 2

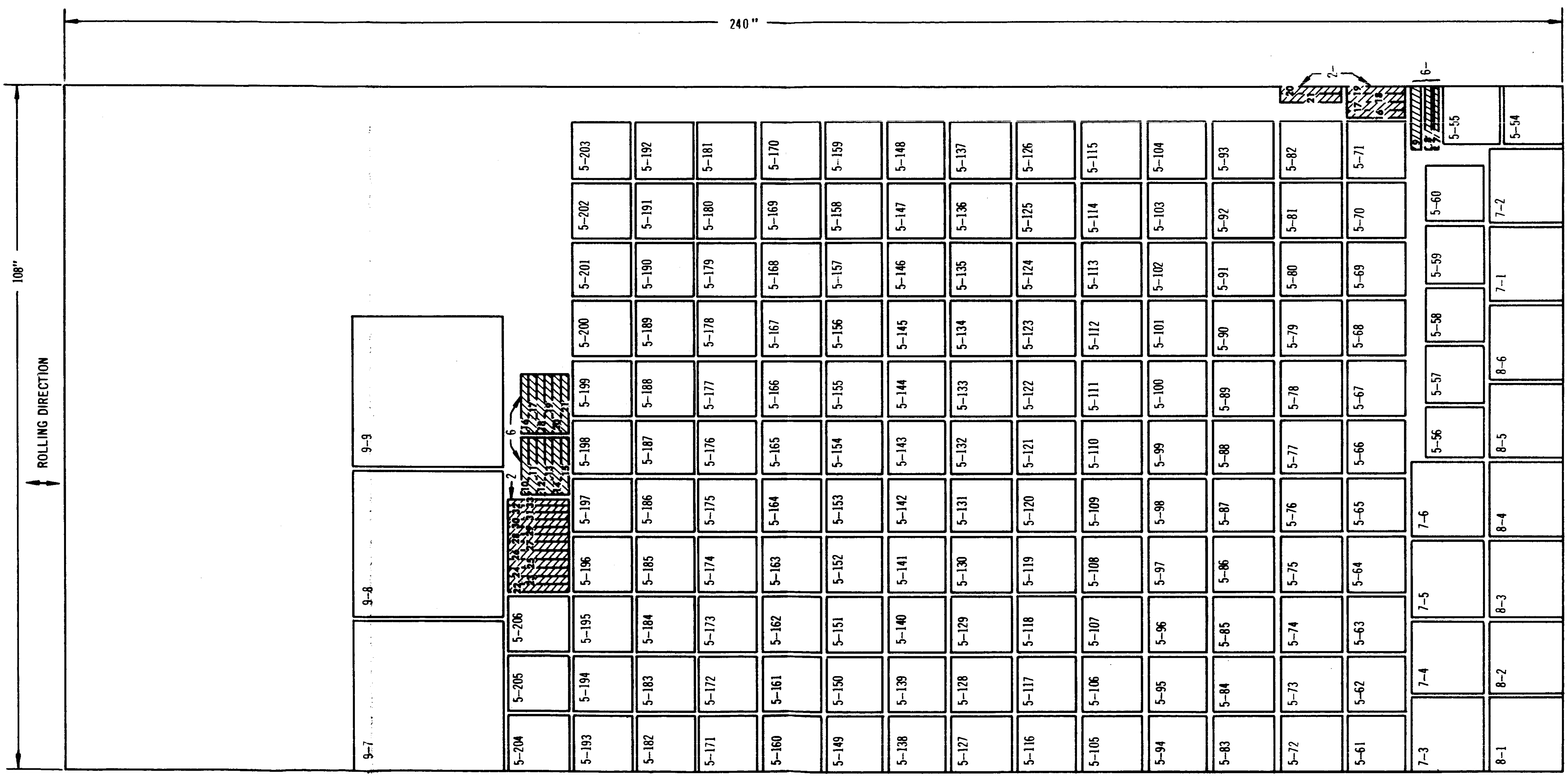


FIGURE 2

LAYOUT, HEAT-1, PLATE NO. 1

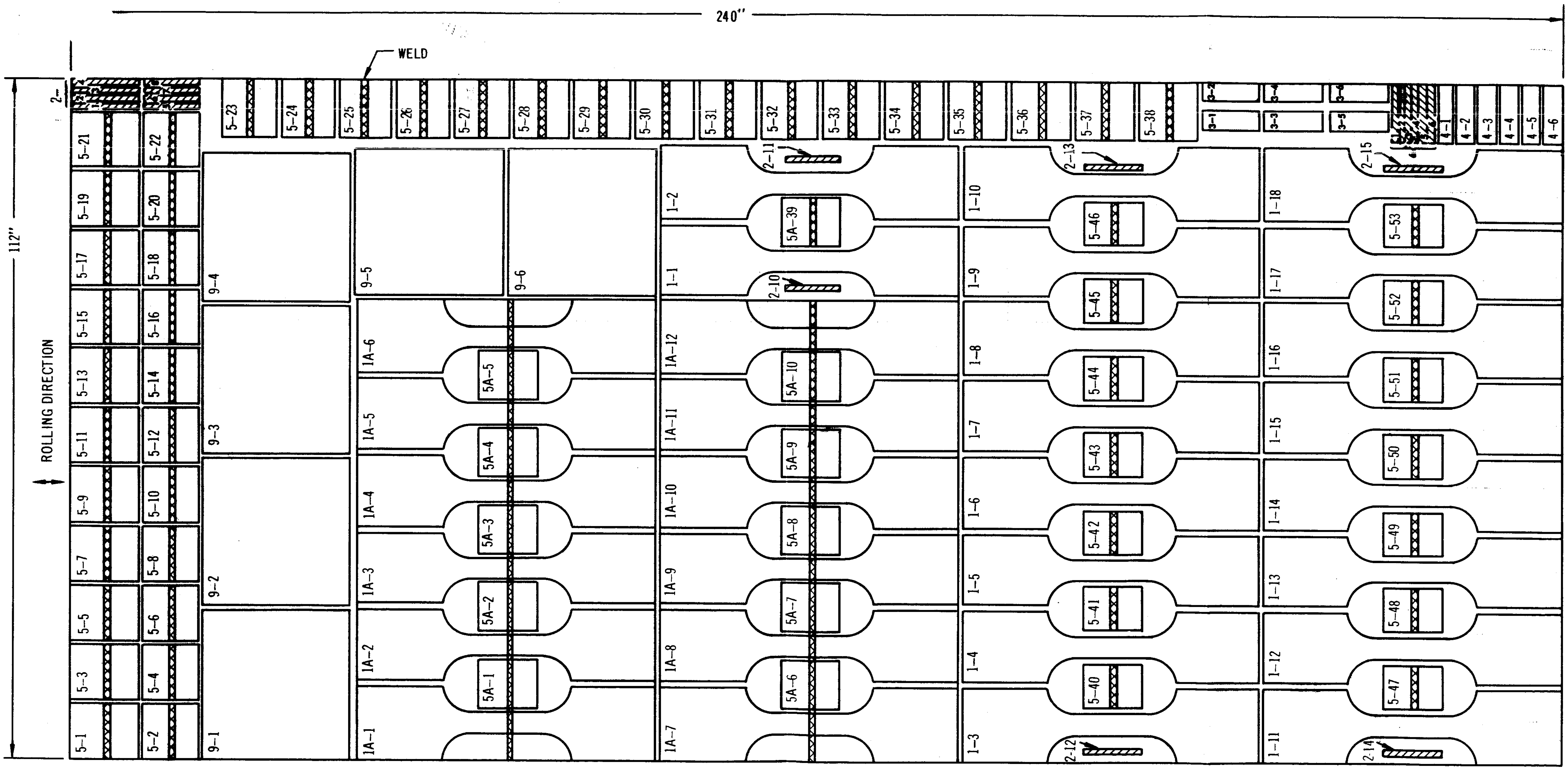
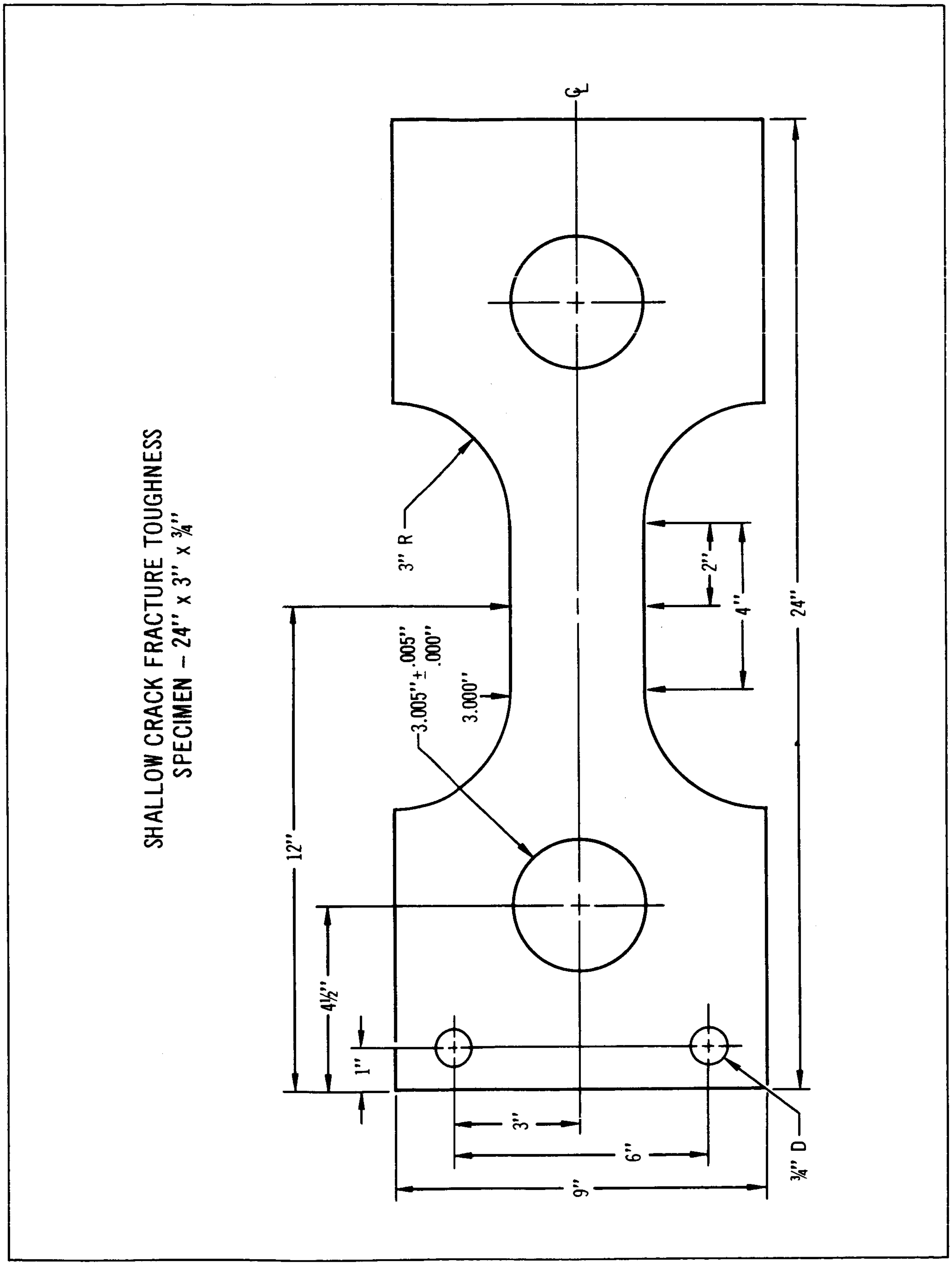
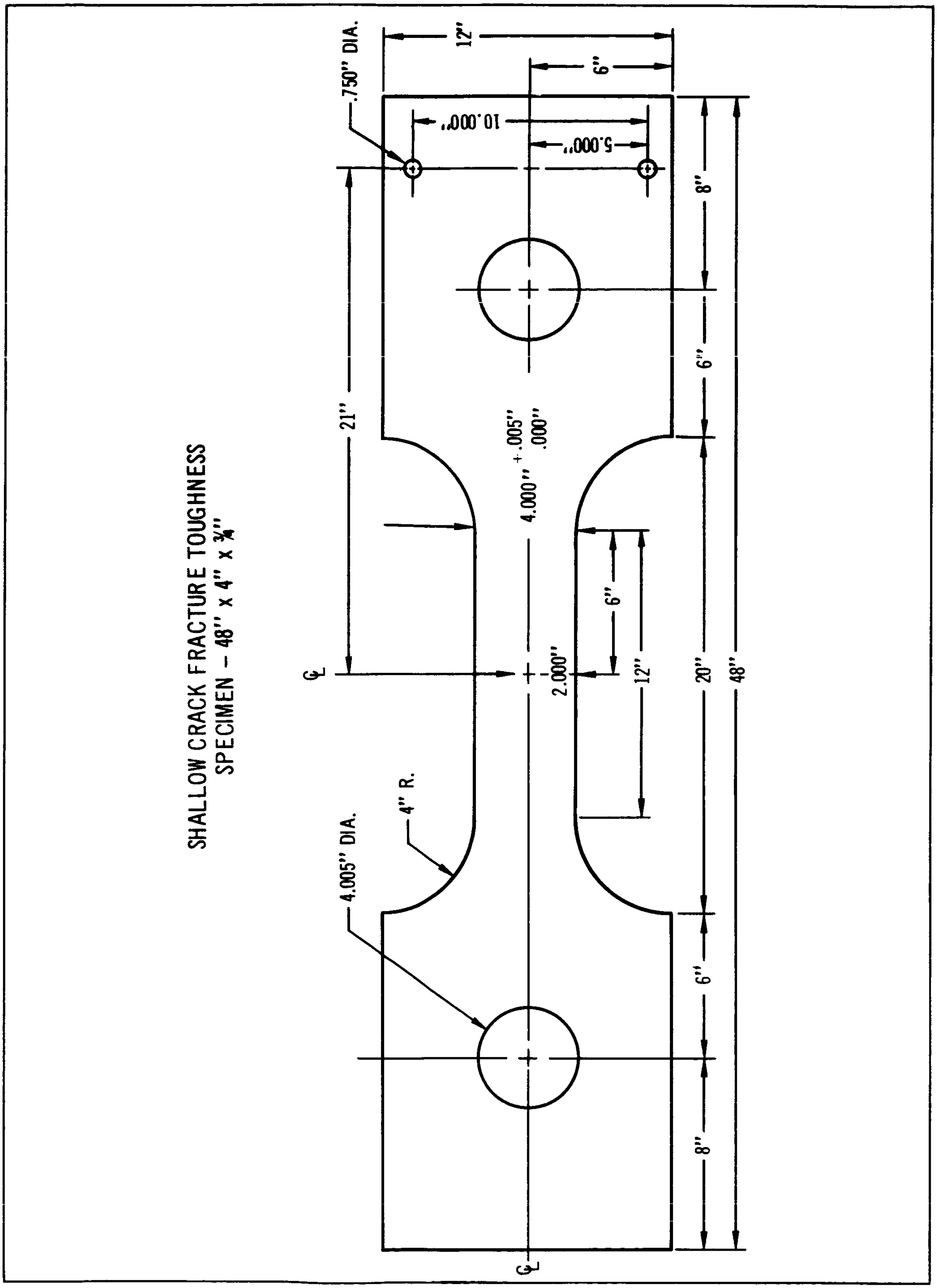


FIGURE 1



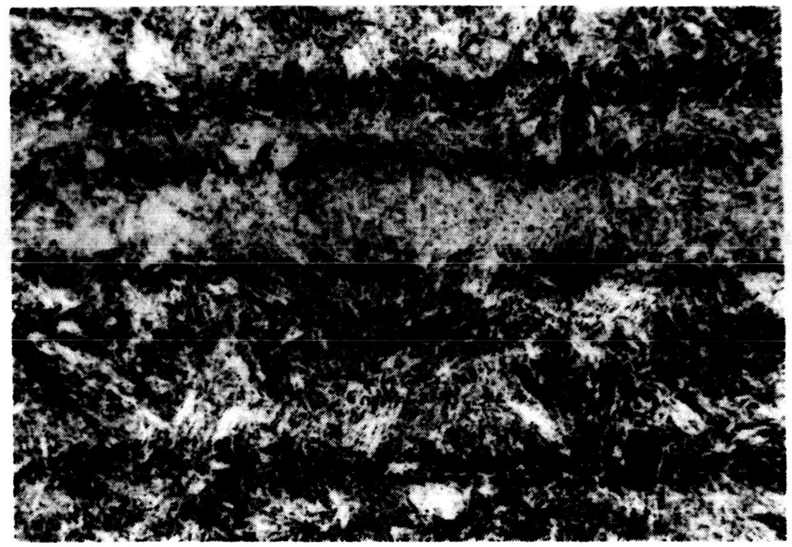
SHALLOW CRACK FRACTURE TOUGHNESS
SPECIMEN – 24" x 3" x 3/4"
℄
3" R
3.005" ± .005" .000"
3.000"
12"
4½"
1"
2"
4"
24"
3"
6"
9"
¾" D

FIGURE 5

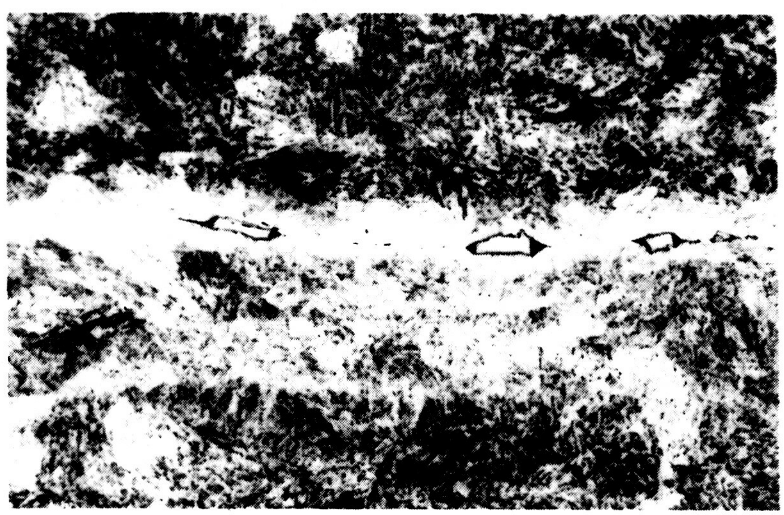


SHALLOW CRACK FRACTURE TOUGHNESS
SPECIMEN – 48" x 4" x ¾"

FIGURE 6



A



B

AS RECEIVED HEAT – A PLATE
TRANSVERSE SECTIONS ILLUSTRATING
CHARACTERISTIC BANDED APPEARANCE (A)
AND OCCASIONAL INCLUSIONS (B)
MIXED ACIDS PLUS CUPRIC CHLORIDE ETCH 250 X

FIGURE 7

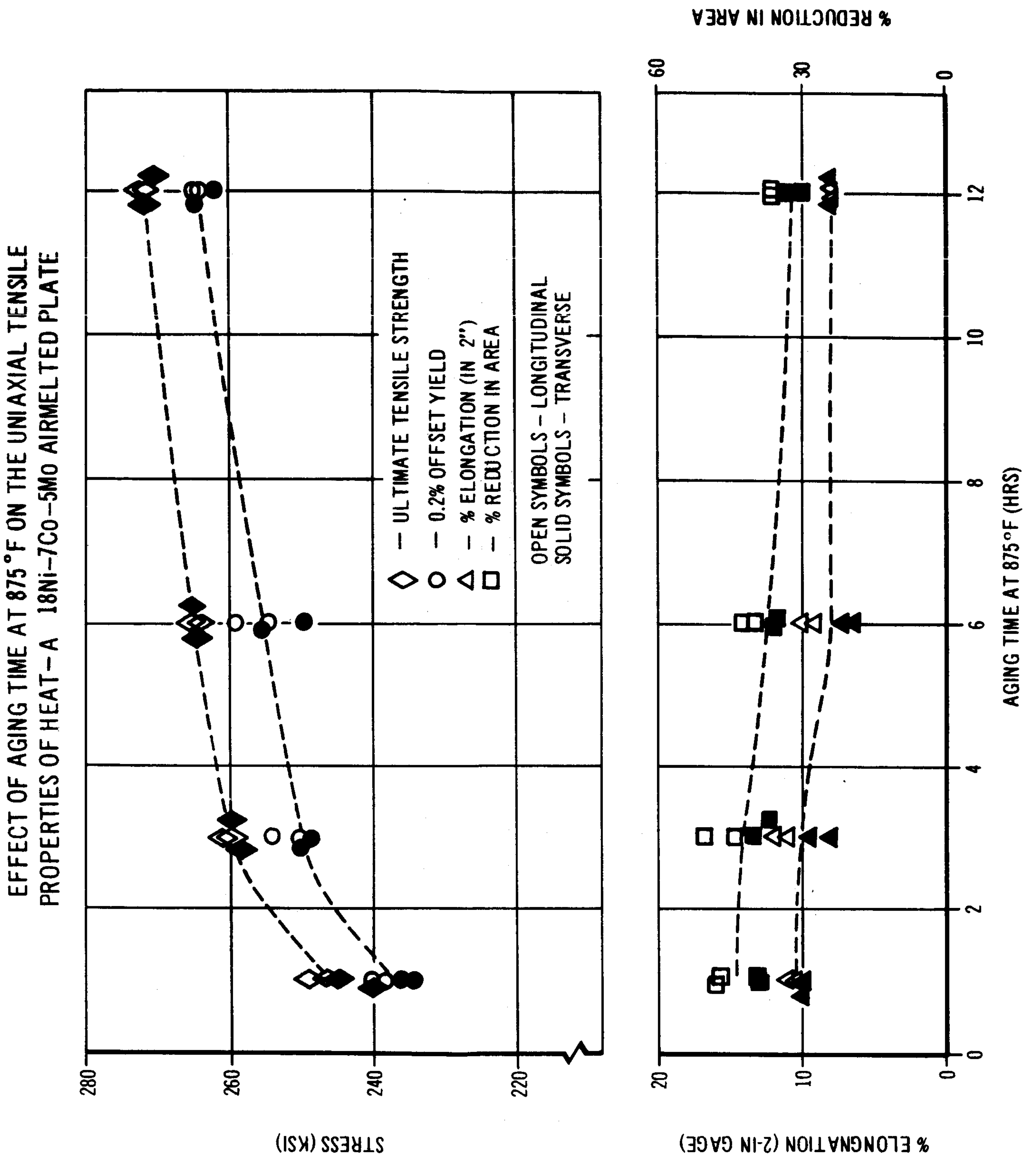
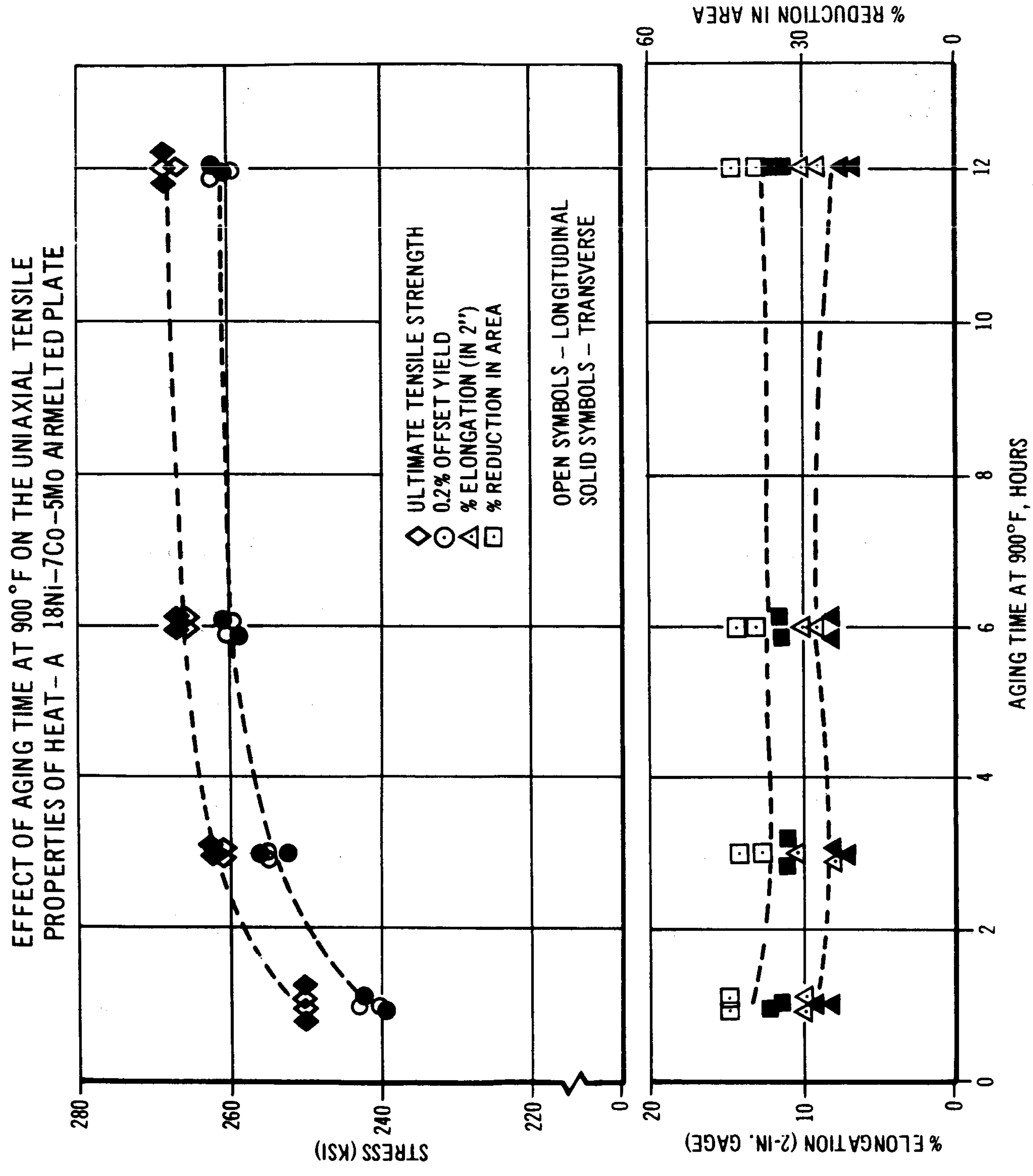
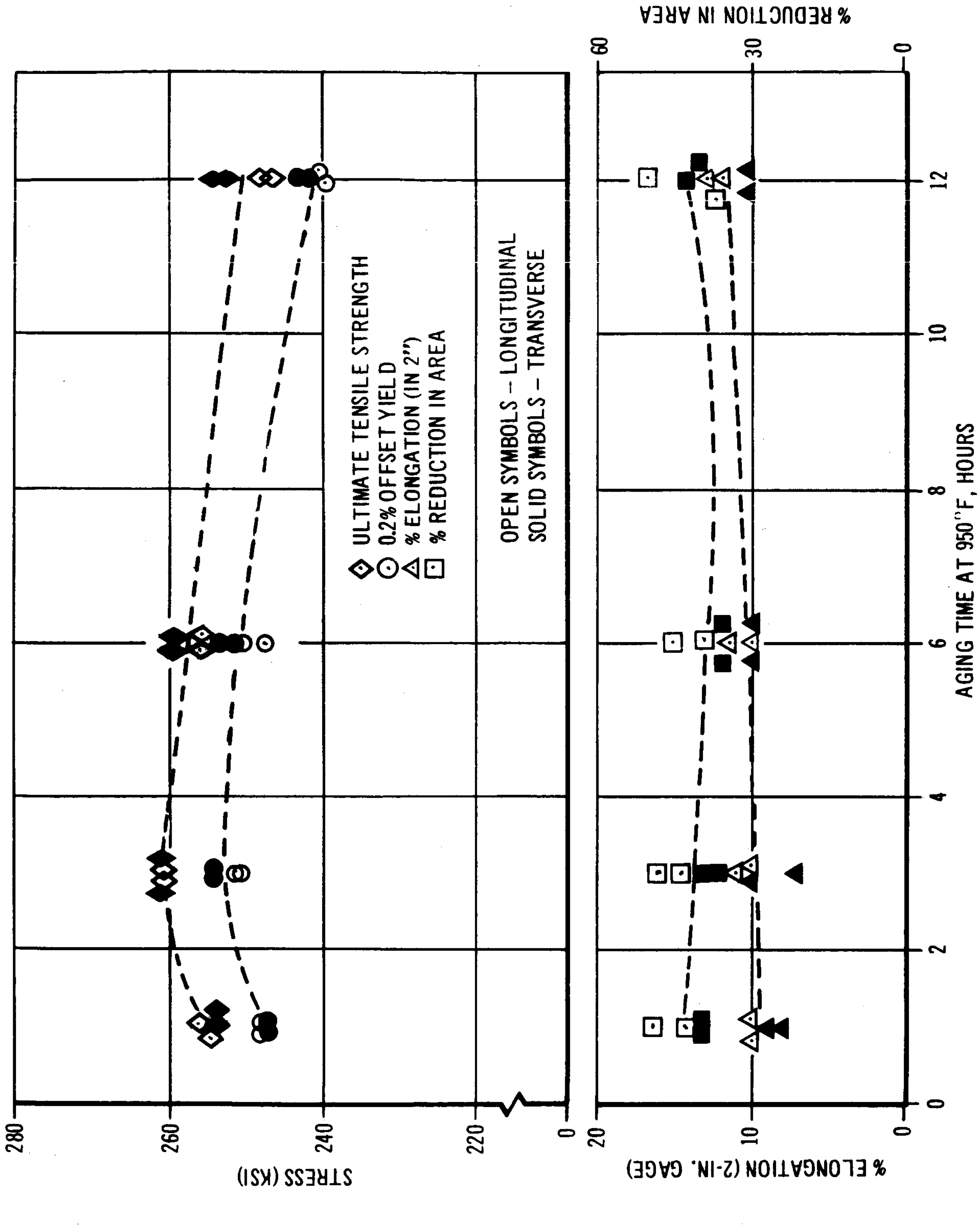

EFFECT OF AGING TIME AT 875°F ON THE UNIAXIAL TENSILE
PROPERTIES OF HEAT-A 18Ni-7Co-5Mo AIRMELTED PLATE
◇ — ULTIMATE TENSILE STRENGTH
○ — 0.2% OFFSET YIELD
△ — % ELONGATION (IN 2")
□ — % REDUCTION IN AREA
OPEN SYMBOLS - LONGITUDINAL
SOLID SYMBOLS - TRANSVERSE
STRESS (KSI)
280
260
240
220
% ELONGATION (2-IN GAGE)
20
10
0
% REDUCTION IN AREA
60
30
0
0
2
4
6
8
10
12
AGING TIME AT 875°F (HRS)

FIGURE 8



EFFECT OF AGING TIME AT 900°F ON THE UNIAXIAL TENSILE PROPERTIES OF HEAT - A 18Ni-7Co-5Mo AIRMELTED PLATE
ULTIMATE TENSILE STRENGTH
0.2% OFFSET YIELD
% ELONGATION (IN 2")
% REDUCTION IN AREA
OPEN SYMBOLS - LONGITUDINAL
SOLID SYMBOLS - TRANSVERSE
STRESS (KSI)
280
260
240
220
0
% ELONGATION (2-IN. GAGE)
20
10
0
% REDUCTION IN AREA
60
30
0
0
2
4
6
8
10
12
AGING TIME AT 900°F, HOURS

FIGURE 9



EFFECT OF AGING TIME AT 950°F ON THE UNIAXIAL TENSILE PROPERTIES OF HEAT – A 18Ni-7Co-5Mo AIRMELTED PLATE

FIGURE 10

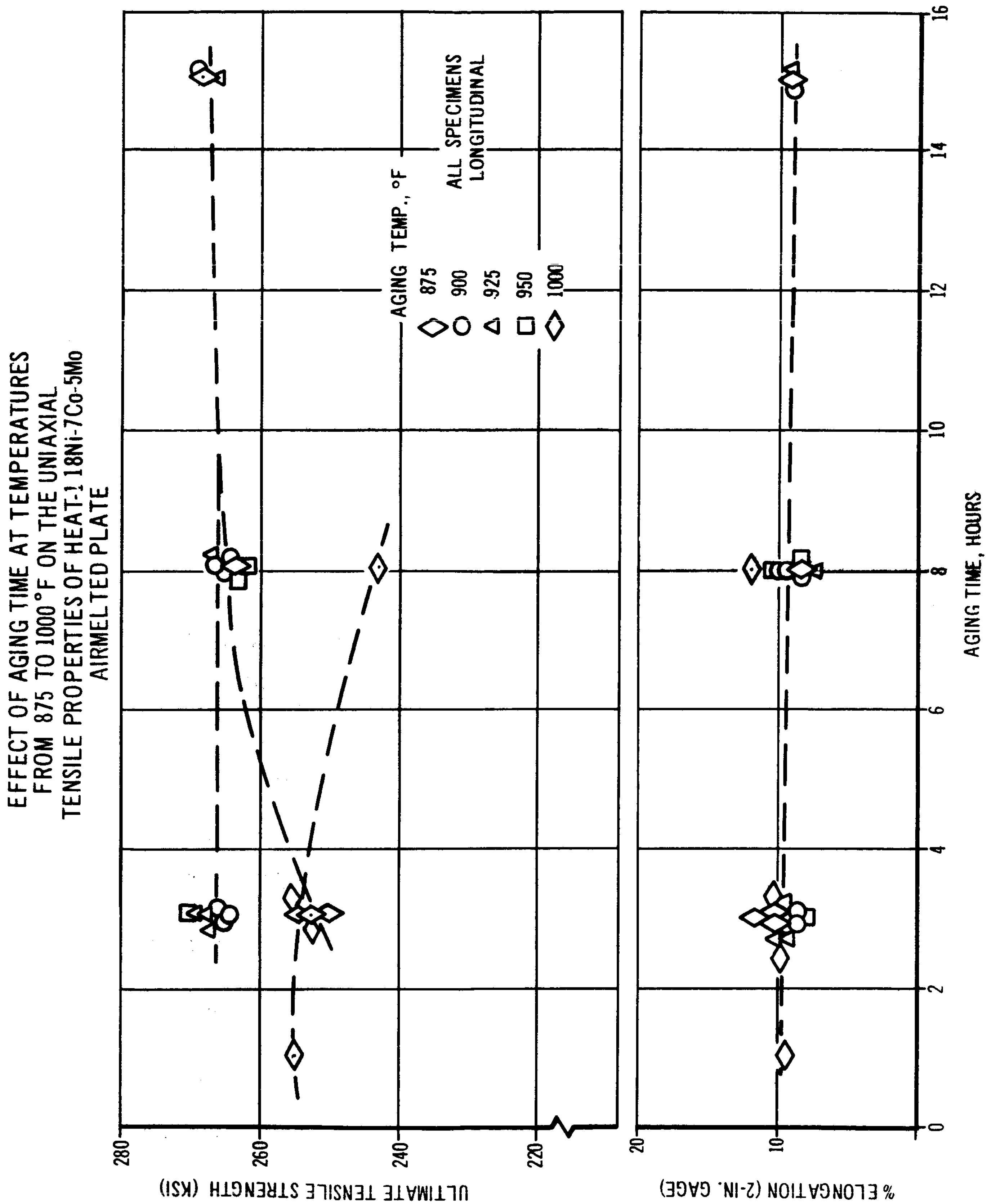

EFFECT OF AGING TIME AT TEMPERATURES FROM 875 TO 1000°F ON THE UNIAXIAL TENSILE PROPERTIES OF HEAT-1 18Ni-7Co-5Mo AIRMELTED PLATE
AGING TEMP., °F
875
900
925
950
1000
ALL SPECIMENS LONGITUDINAL
ULTIMATE TENSILE STRENGTH (KSI)
280
260
240
220
% ELONGATION (2-IN. GAGE)
20
10
AGING TIME, HOURS
0
2
4
6
8
10
12
14
16

FIGURE 11

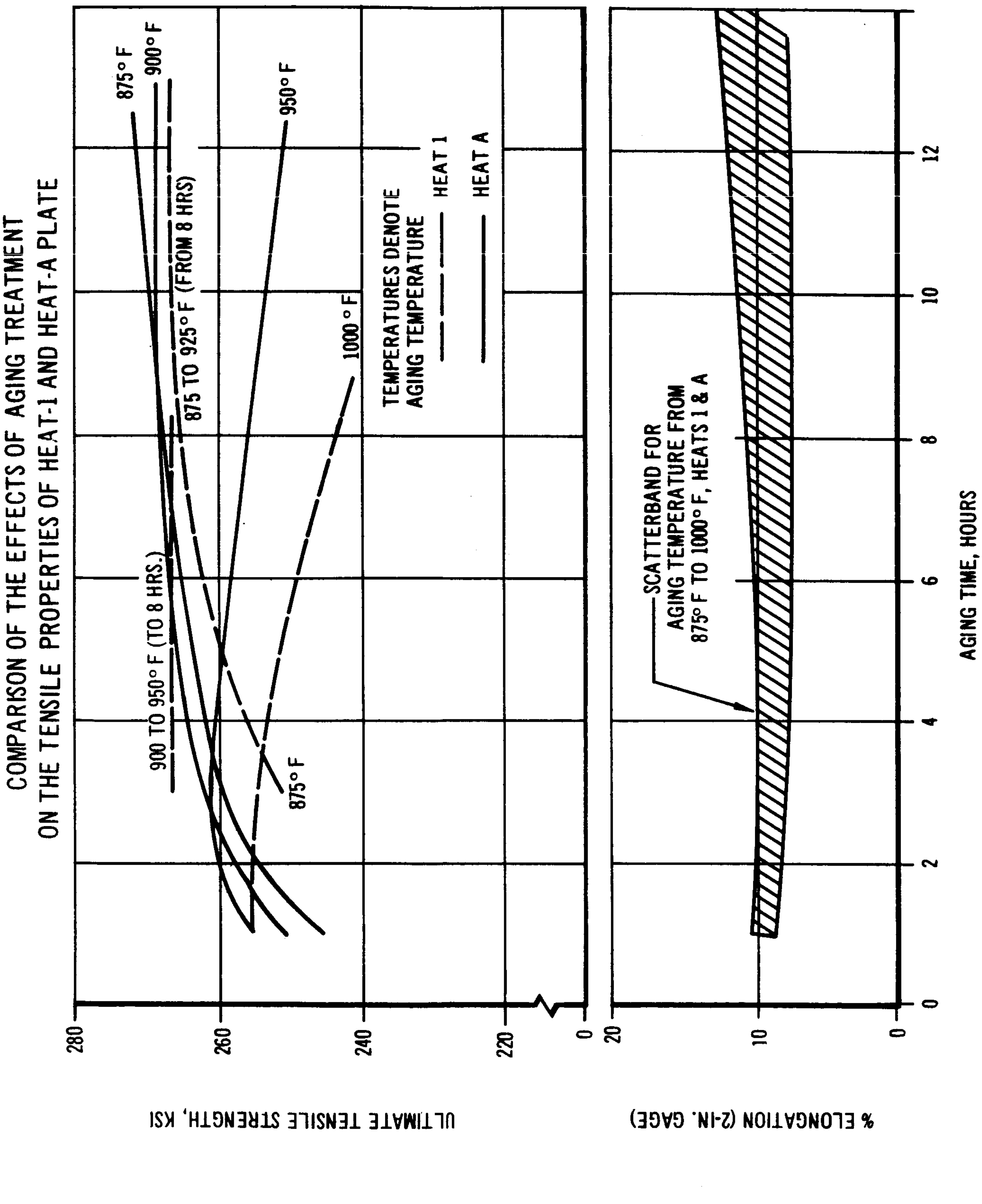

COMPARISON OF THE EFFECTS OF AGING TREATMENT
ON THE TENSILE PROPERTIES OF HEAT-1 AND HEAT-A PLATE
875° F
900° F
950° F
875 TO 925° F (FROM 8 HRS)
1000° F
900 TO 950° F (TO 8 HRS.)
875° F
TEMPERATURES DENOTE
AGING TEMPERATURE
HEAT 1
HEAT A
SCATTERBAND FOR
AGING TEMPERATURE FROM
875° F TO 1000° F, HEATS 1 & A
ULTIMATE TENSILE STRENGTH, KSI
280
260
240
220
0
% ELONGATION (2-IN. GAGE)
20
10
0
AGING TIME, HOURS
0
2
4
6
8
10
12

FIGURE 12

EFFECT OF AGING TIME AT 850, 875, 900, AND 950°F
ON THE HARDNESS OF HEAT-1 18Ni–7Co–5Mo AIRMELTED PLATE

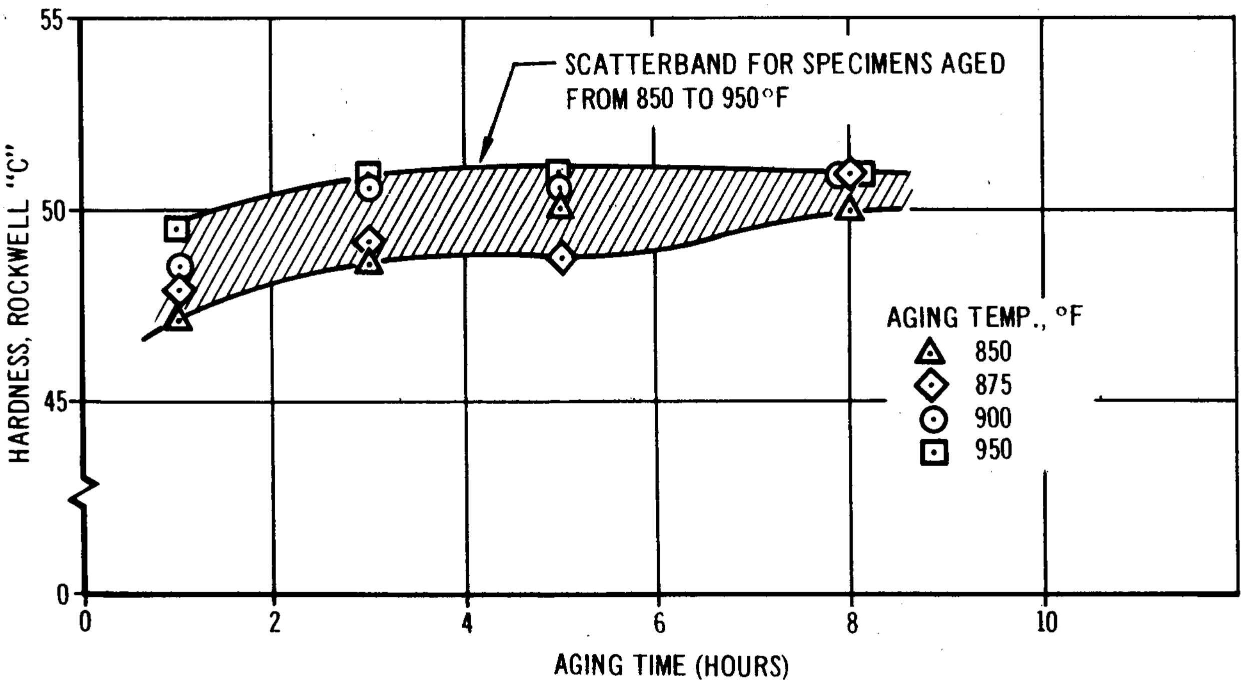


FIGURE 13

EFFECT OF AGING TIME AT 875, 900 AND 950°F
ON THE HARDNESS OF HEAT-A 18Ni-7Co-5Mo AIRMELTED PLATE

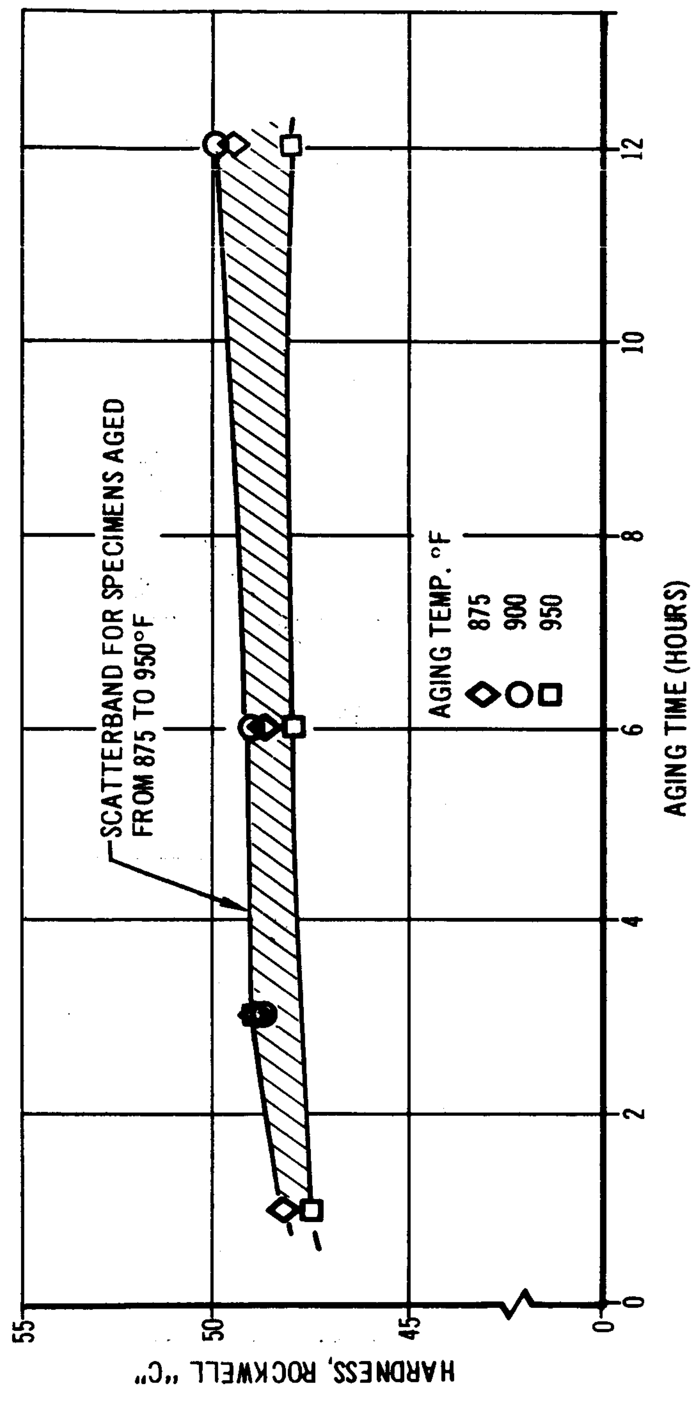


FIGURE 14

EFFECT OF CRACK DEPTH ON THE NET FRACTURE
STRESS OF ¾-IN. THICK AIRMELTED 18Ni-7Co-5Mo PLATE

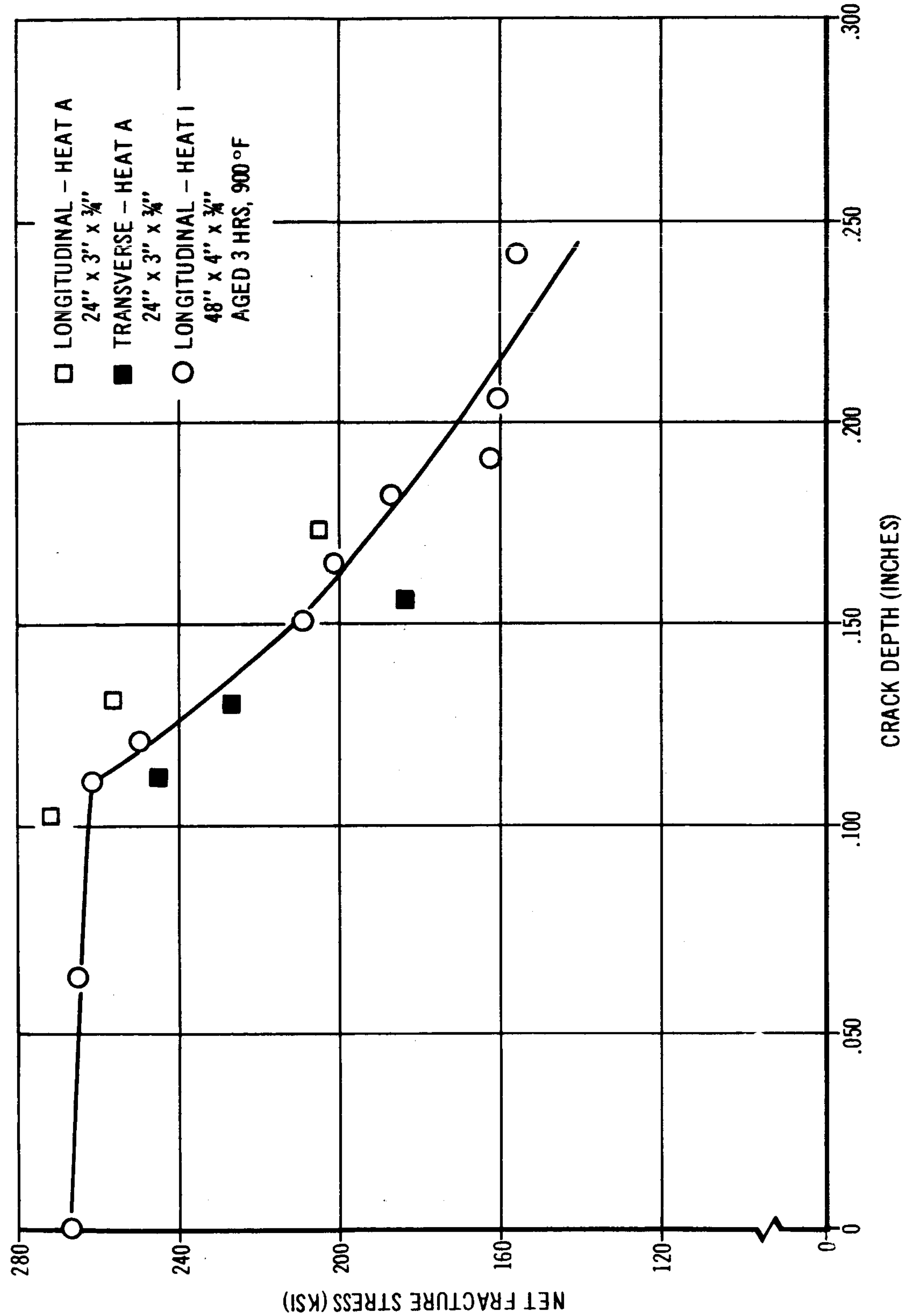
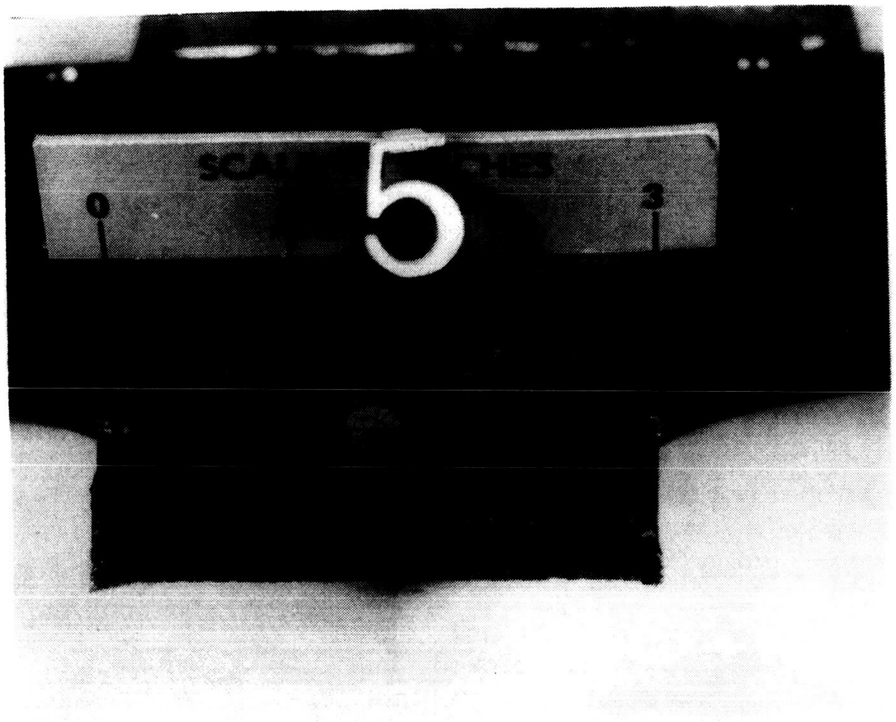
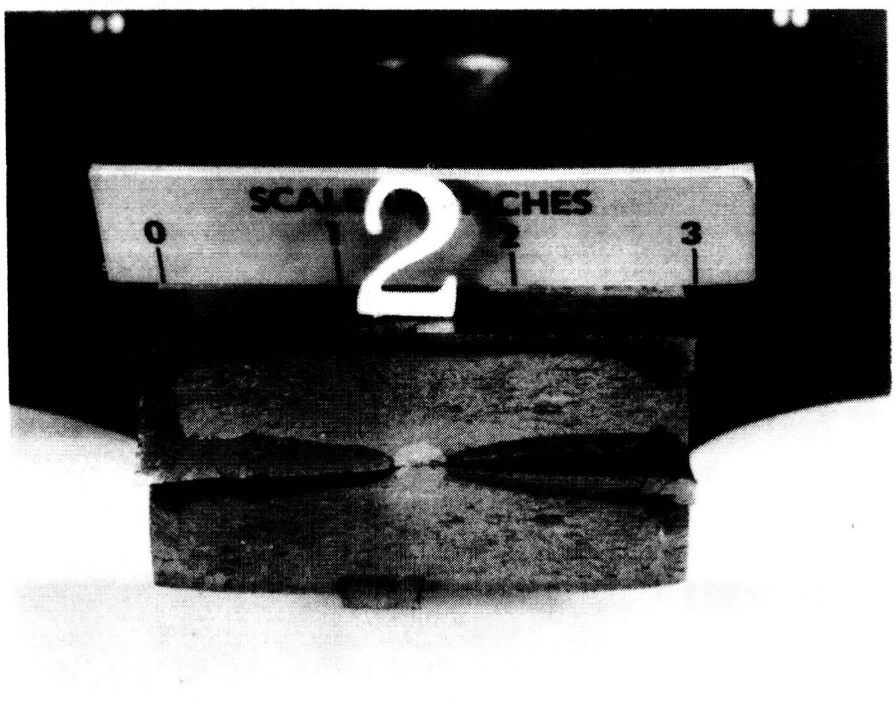


FIGURE 15



TRANSVERSE SPECIMEN AP4-5



LONGITUDINAL SPECIMEN AP4-2
TYPICAL SHALLOW-CRACK SPECIMEN FRACTURE
SURFACES. HEAT–A PLATE.

FIGURE 16

APPENDIX I

TENTATIVE DOUGLAS MATERIAL SPECIFICATION, DMS-1835, (REVISED 4-11-63)
STEEL PLATE, 18% NICKEL MARAGING, 240,000 psi YIELD STRENGTH

ACKNOWLEDGEMENT
A vendor shall mention this specification number and its revision letter in all quotations and when acknowledging purchase orders.

FORM
Plate

APPLICATION
The material covered by this specification is primarily intended for use in welded motor case assemblies at yield strengths of 240,000 psi.

APPLICABLE DOCUMENTS
The following documents of issue in effect on date of invitation for bids, form a part of this specification:

Federal	
Test Methods Std. No. 151	Metals: Test Methods
Aeronautical Material Specifications	
AMS 2252	Tolerance, Alloy Steel Sheet, Strip and Plate
American Society for Testing Materials	
ASTM E 45 Method A	Determining Inclusion Content of Steel
ASTM Standards, 1958, Part 3	Metals, Test Methods
ASTM, 1956	Standard Method for Chemical Analysis of Ferrous Metals
ASTM A-435-59T	Specification for Ultrasonic Testing and Inspection of Steel Plates
Military	
MIL-STD-430	Macrograph Standards for Steel Bars, Billets and Blooms

APPENDIX I, Con't.

COMPOSITION

The composition shall be as follows:

Element	Chemical Content, Weight %
Nickel	17.0 - 19.0
Cobalt	7.0 - 8.5
Molybdenum	4.6 - 5.10
Titanium	0.40 - 0.60
Carbon	0.03 max
Silicon	0.10 max
Manganese	0.10 max
Sulfur	0.01 max
Phosphorus	0.01 max
Aluminum	0.05 - 0.15
Boron	0.003 max added
Zirconium	0.02 added
Calcium	0.05 added

MELTING PRACTICE

The steel shall be manufactured by acceptable electric furnace air melting practices with or without vacuum degassing.

CONDITION

The plate shall be furnished hot rolled, annealed, completely descaled, and protected against corrosion.

Annealing Practices

Annealing shall consist of heating the plate in air to 1500 ± 25°F for one hour per inch of cross section or one hour minimum time at temperature, whichever is applicable, followed by air cooling to room temperature.

Hardness

Plate supplied in the annealed condition shall have a Rockwell "C" scale hardness value of 34 maximum, or 341 Brinell, maximum.

Corrosion Protection

All surfaces shall be free of rust and contamination and protected from corrosion as agreed upon by the vendor and purchaser.

TECHNICAL REQUIREMENTS

Mechanical Properties, Aged

Each plate shall be tested in directions parallel to and perpendicular to the finish rolling direction, after heat treatment at two cycles (noted below), and shall meet the following minimum properties:

APPENDIX I, Con't.

Ultimate Tensile Strength, psi, minimum	245,000
Yield Strength, 0.2% Offset. psi, minimum	240,000
Elongation, % in 2 inches, minimum	6
Reduction in Area, % minimum (round bar test)	30

The material shall be heat treated as follows:

Cycle 1:	900 $\pm$ 15°F, 3 hours, air cool
Cycle 2:	900 $\pm$ 15°F, 12 hours, air cool

Bend Test

Material supplied in the annealed condition shall be capable of sustaining the following maximum bend radius, after bending through an angle of 90° after springback. Specimens shall be bent so that the axes of bend are parallel and transverse to the finish rolling direction.

Maximum bend radius = 2T (where T = thickness of plate).

Cleanliness

Every plate must be sampled for microcleanliness. Limits shall conform to the requirements of ASTM E-45-Method A, thin and heavy series as follows:

	Thin	Heavy
A	1.0	1.5
B	1.0	1.5
C	1.0	1.5
D	1.5	1.5

Internal Soundness

Internal soundness shall be determined by ultrasonic test techniques in conformance with ASTM A-435-59T. Longitudinal wave 100% surface inspection with rejection limits of 40% on 2-1/2" back reflection.

QUALITY

The plate shall be uniform in quality and condition, clean, sound, smooth, and free from foreign materials and from internal and external defects detrimental to fabrication or performance of parts. The surface shall be free of pits, scratches, seams, laps, or other defects. Surface defects may be removed by grinding so long as minimum dimensional tolerances are not exceeded, and grinding takes place prior to final annealing.

TOLERANCES

Thickness, width, length, and flatness tolerances of plate shall conform to the latest issue of AMS 2252. In addition, the thickness tolerance shall not exceed plus 0.060 inch, minus 0.01 inch for plate 1-inch thick or less, regardless of width or length.

Code 18355

DOUGLAS AIRCRAFT COMPANY, INC.

DOUGLAS LABORATORY PROCEDURE

DLP 13.822

ISSUE OF 6-27-62

PAGE OF

TITLE: **TECHNIQUE FOR MAKING SHALLOW-CRACKS IN SHEET METAL TENSILE SPECIMENS**

A. SCOPE & USE:

This Laboratory Procedure describes the method for making shallow-cracks in sheet metal tensile specimens.

B. EQUIPMENT:

1. 3600 RPM 50 lbs. capacity Krouse Sheet Flexure Fatigue Machine.

2. Two wedge type support blocks to clamp the specimen (Figures 1 and 2). These blocks should be made of a material that is as hard or harder than the specimen material. 4340 steel support blocks hardened to RC 53 have been used successfully for high-strength steel specimens.

3. Two adapter blocks to attach the specimen to the connecting rod of the fatigue machine. (Figures 3 and 4).

4. 40 power microscope with an eyepiece scale graduated in 0.001".

C. SPECIMEN PREPARATION:

1. The specimen used is a pin-loaded tensile specimen as shown in Figure 5.

2. The specimen which is to be cracked is ground or sanded so that the grinding or sanding striations are in the longitudinal direction of the specimen (normal to the crack length). It may be necessary to grind both sides of the specimen to maintain flatness. In grinding, not more than 0.001 inch thickness of material is removed with one pass. Preferably, high-strength steel is ground in the annealed condition to prevent grinding cracks and burning.

3. An electrical discharge machined starter notch (0.003 inch deep, 0.004 inch wide and 0.006 inch long) is made in the specimen at the desired location of the shallow-crack.

C. (Cont'd)

4. The specimen is then heat treated to the desired strength level, if required, using heat treat fixtures where necessary to maintain flatness.

5. The sharp corners and the specimen surface, on which the shallow-crack is to be introduced, are polished using No. 100 abrasive cloth first and finished with No. 1 abrasive polishing paper. The specimen is always polished in the longitudinal direction of the specimen.

D. PROCEDURE:

1. The specimen is placed (polished surface facing up) between the two wedge-shaped support blocks and its position adjusted so that the electrical discharge machined starter notch is located approximately 1/16 inch directly in front of the tip of the top wedge shaped block. (Figures 6 and 7).

2. The free end of the specimen is attached to the connecting rod of the fatigue machine by means of the two adapter blocks. (Figures 6 and 7).

3. By means of an adjustment screw near the fixed end of the specimen, the height of the specimen is adjusted so that the stress on the polished top surface of the specimen is always tension, never compression.

4. The eccentric of the fatigue machine is adjusted so that the initial crack occurs within a convenient time, about 3 to 5 minutes. An eccentricity of 16 to 20 divisions (deflection of 0.48 to 0.59 inch respectively) is satisfactory for high-strength steel.

5. The microscope is focused on the polished top surface of the specimen so that the electrical discharge machined starter notch is visible in the center of the field of view. (Figure 7).

D. (Cont'd)

6. The fatigue machine is then turned on and allowed to run for a short time, one or two minutes. The fatigue machine is then stopped and the specimen surface viewed through the microscope to see if a crack has initiated from the starter notch. If there is no crack, the fatigue machine is run again for a short time and the specimen surface viewed again. This procedure is repeated until a crack has initiated from the starter notch. The crack length is then measured with the graduated eyepiece of the microscope. Cycling is continued until the desired crack length is obtained. Approximate relations between crack length and crack depth for 0.070 inch high-strength steel, 0.050 inch 6Al-4V Titanium, 0.050 inch 5Al-2.5 SN Titanium, 0.100 inch and 0.250 inch 2014-T6 Aluminum are presented in Figures 8 and 9.

7. The crack length and number of cycles are recorded and the specimen is removed from the fatigue machine.

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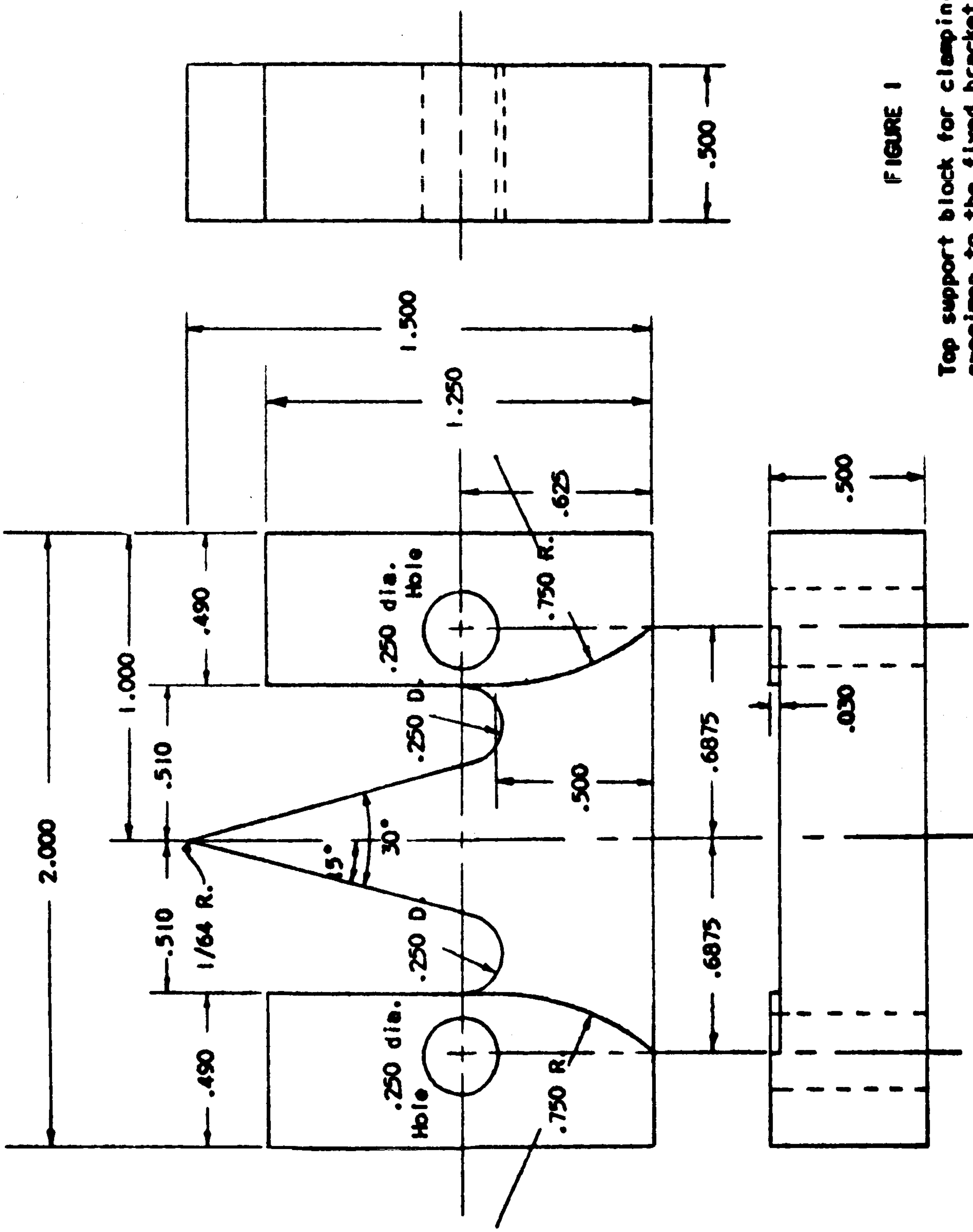


FIGURE I

Top support block for clamping the specimen to the fixed bracket of the fatigue machine.

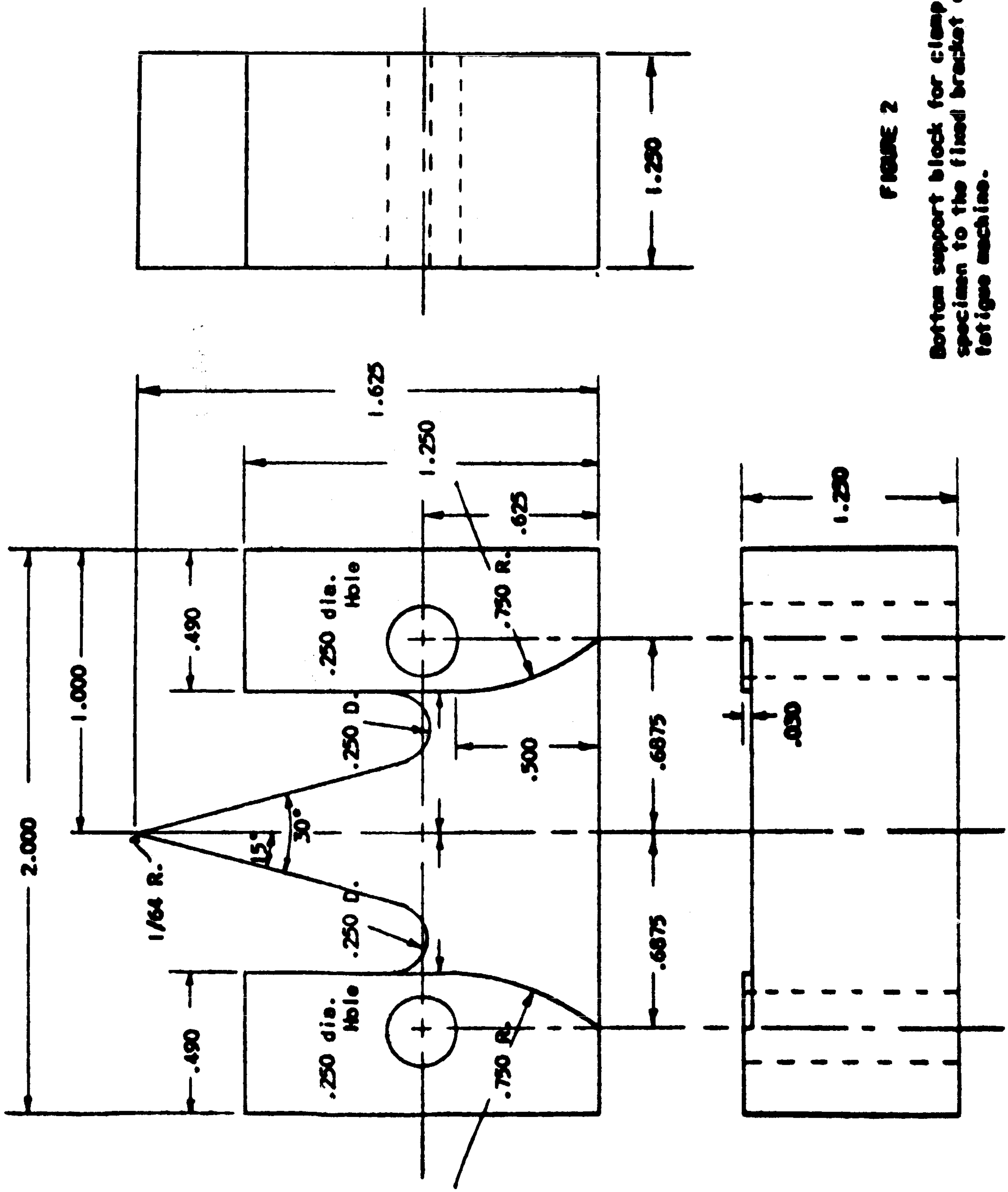


FIGURE 2

Bottom support block for clamping the specimen to the fixed bracket of the fatigue machine.

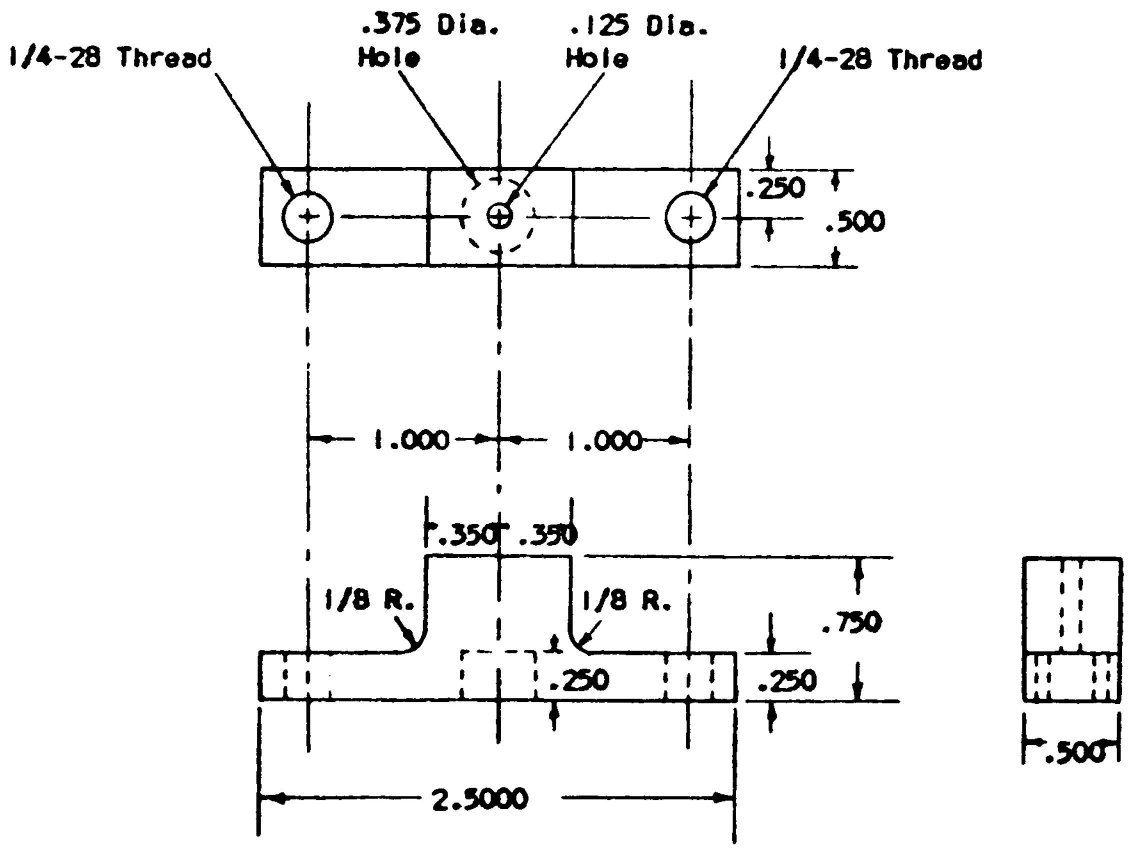


FIGURE 3

Top adapter block for attaching the specimen to the connecting rod of the fatigue machine.

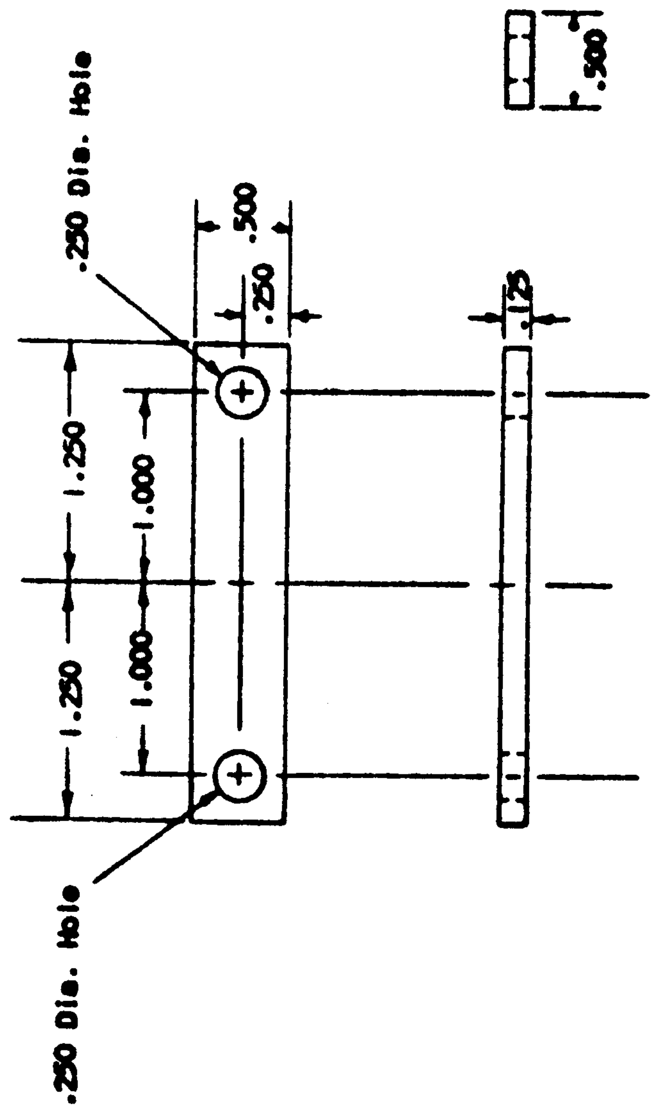
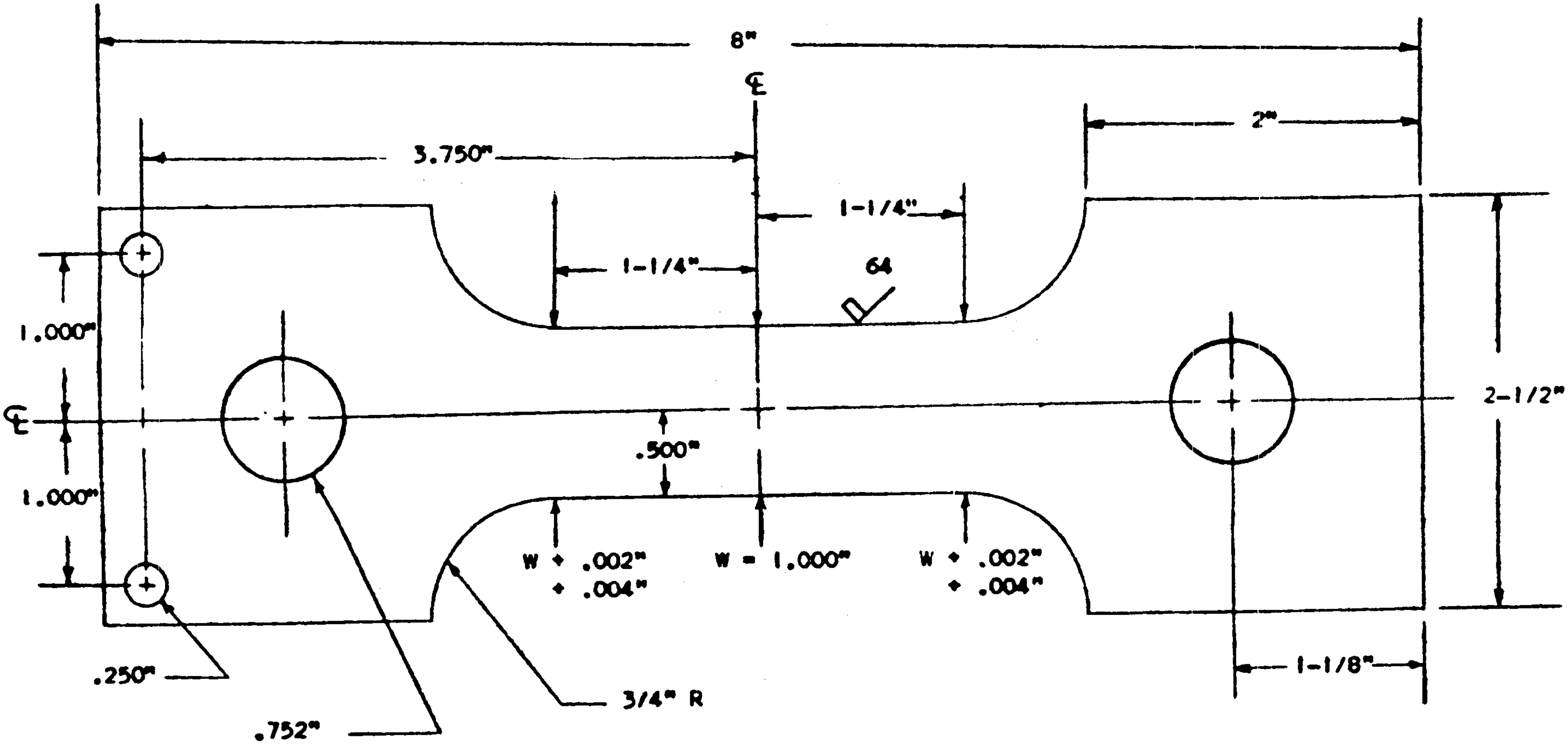


FIGURE 4

Bottom adapter block for attaching the specimen to the connecting rod of the fatigue machine.

FIGURE

SHALLOW CRACKED SHEET TENSILE SPECIMEN



NOTES

1. Gradual equal taper on both sides from outer ends of reduced section towards center as shown with no abrupt changes.
2. Edges of reduced section to be left sharp.
3. Finish is to be RMS 125 except as shown.
4. Holes must be on ℄ within 0.002".

TOLERANCES

Fractions ± 1/32"

Decimal ± 0.002"

Unless otherwise specified.

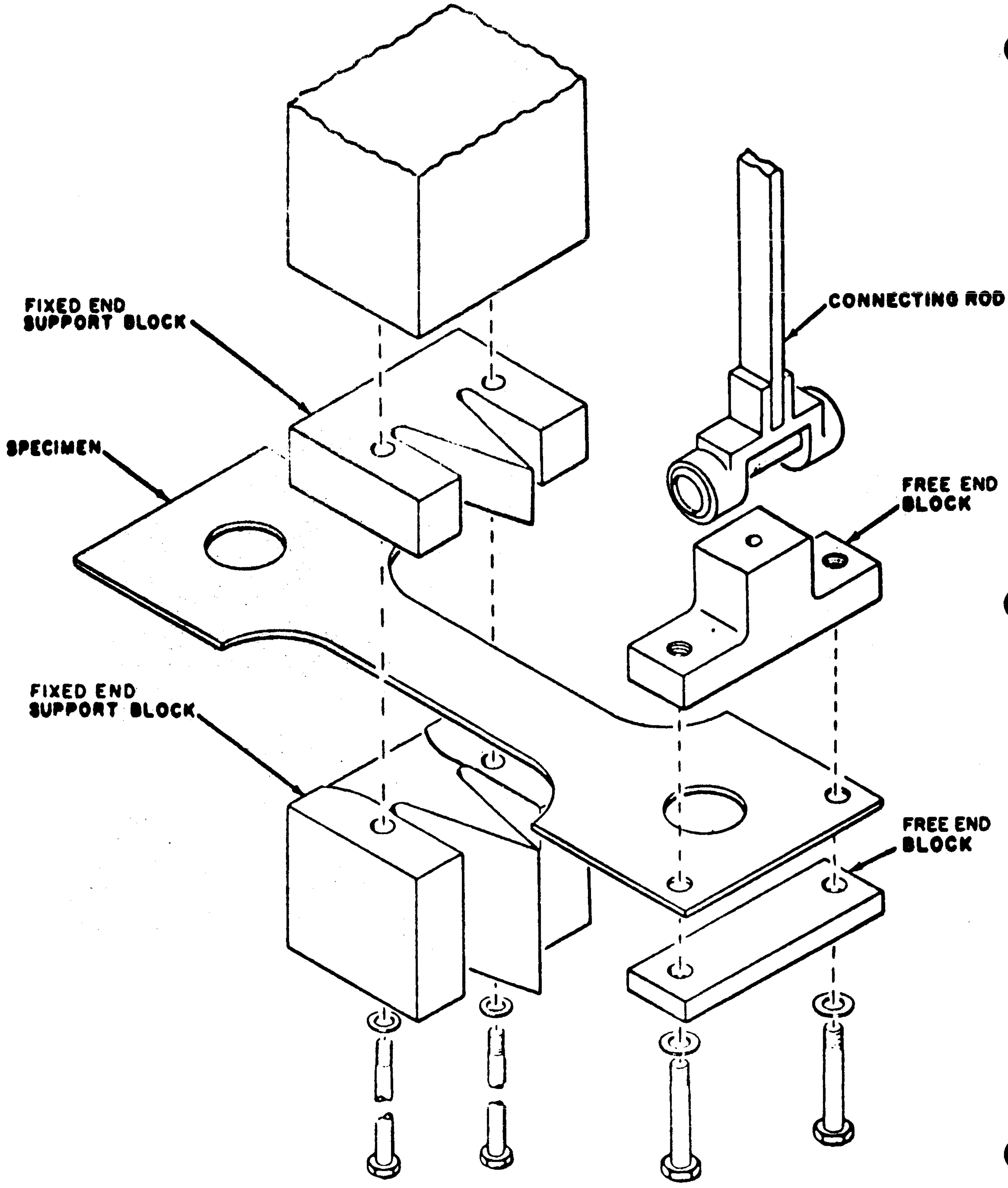


FIGURE 6

Set-up for making shallow crack (exploded view).

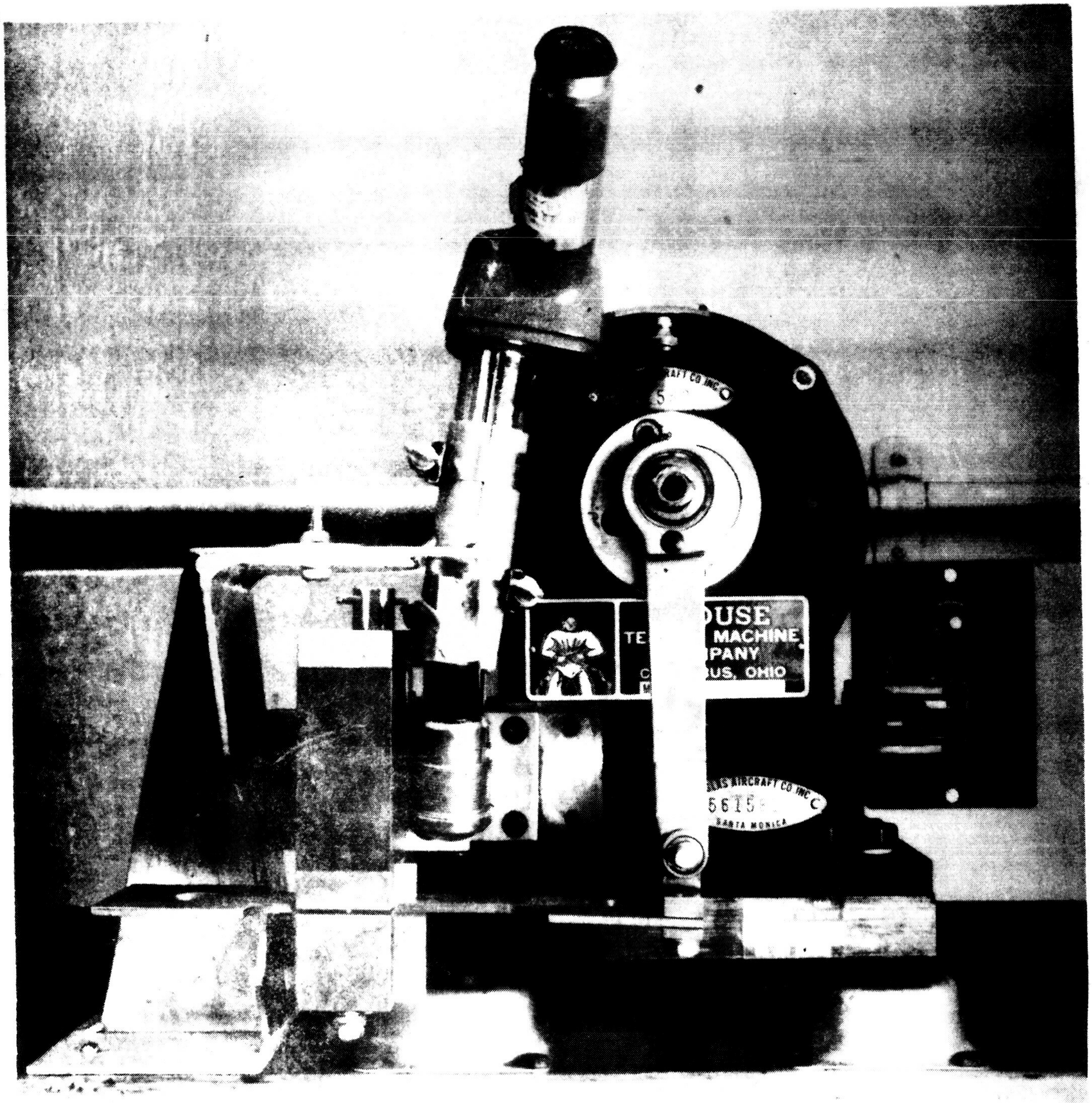


FIGURE 7

SET-UP FOR MAKING SHALLOW CRACKS (FRONT VIEW).

FIGURE 8

Relation between crack length and crack depth of shallow cracks in .070" thick 4340 and H-11 steels H.T. 260 to 280 ksi.

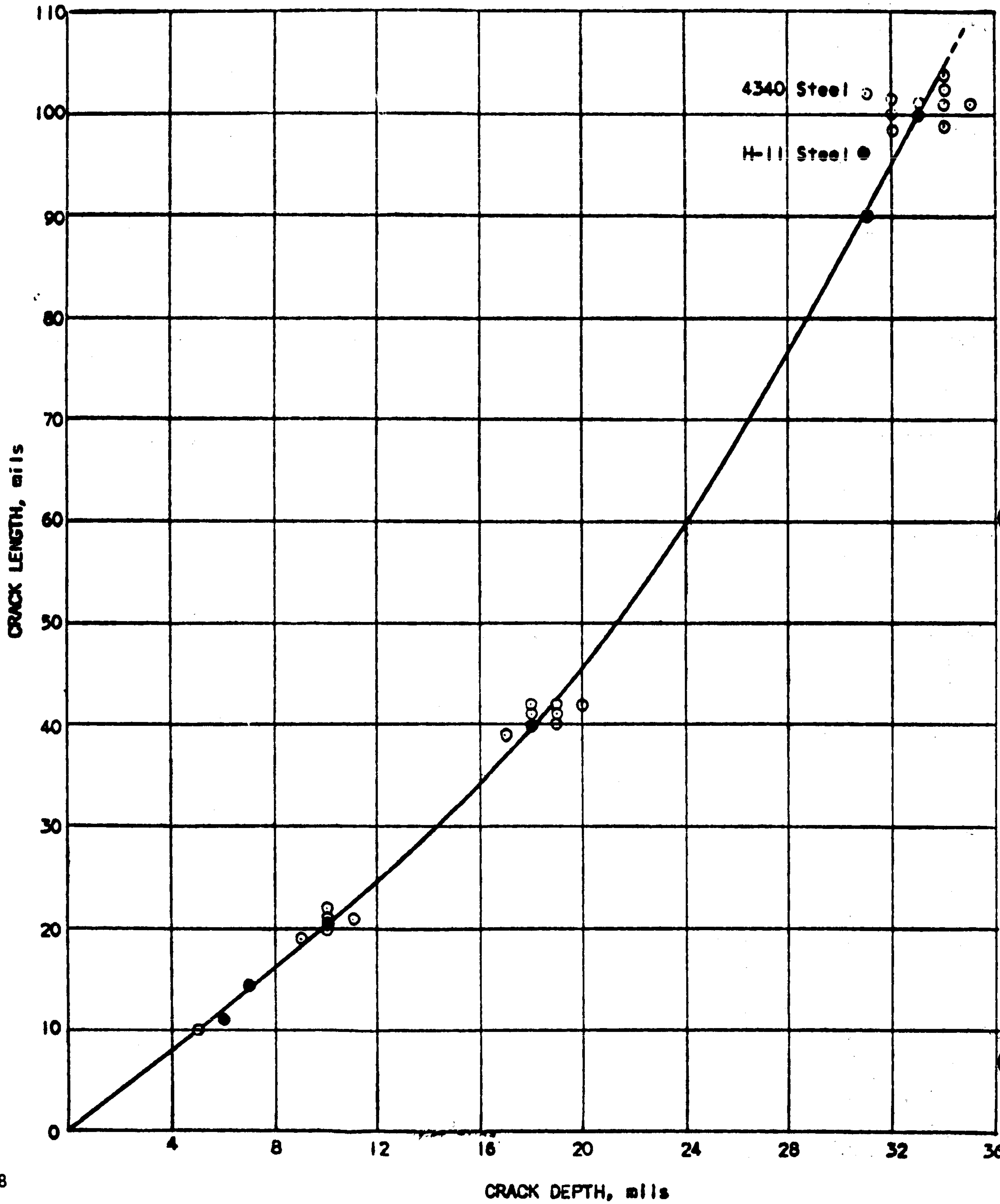
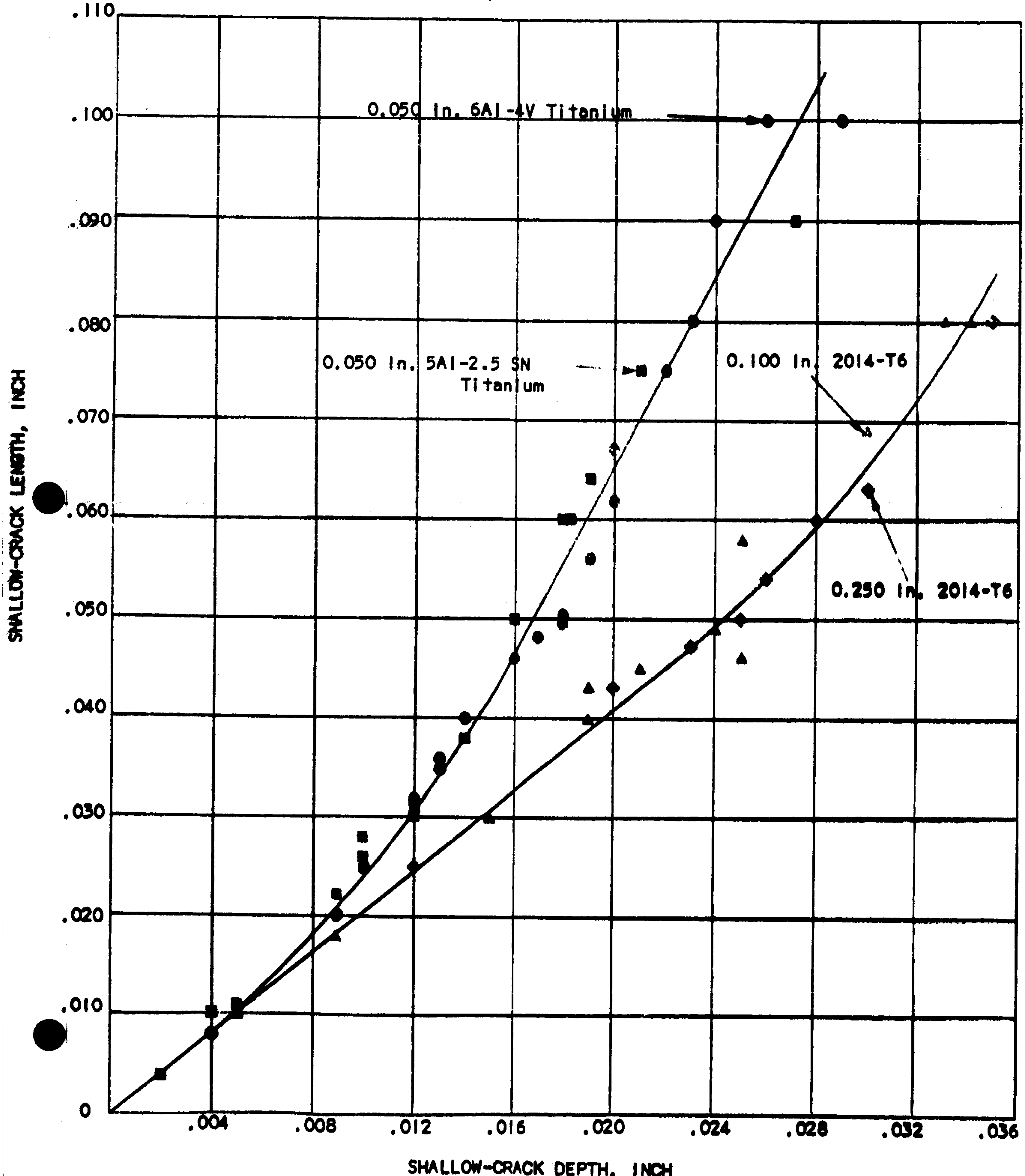


FIGURE 9

RELATION BETWEEN CRACK LENGTH AND CRACK DEPTH OF SHALLOW-CRACKS IN 0.050 IN. 6AL-4V TITANIUM, 0.050 IN. 5AL-2.5 SN TITANIUM, 0.100 IN. AND 0.250 IN. 2014-T6 ALUMINUM.



APPENDIX III - TENSILE DATA SUMMARY

UNIAXIAL TENSILE DATA - HEAT 1 PLATE

SPEC. NO.	AGING TEMP., °F	TIME AT TEMP. HRS.	0.2% YIELD STRESS, ksi	ULTIMATE STRESS, ksi	% ELONG. (2-in. GAGE)
2-4	875	3	247.3	252.5	10.0
2-8	875	3	244.8	250.8	11.0
2-10	875	3	247.8	253.7	10.0
2-22	875	8	NA	263.9	8.0
2-23	875	15	NA	268.3	9.0
2-6	900	3	257.7	264.2	8.5
2-7	900	3	259.1	264.4	8.5
2-8	900	3	260.7	265.2	9.0
2-16	900	8	NA	266.6	9.0
2-24	900	8	NA	265.7	8.0
2-25	900	8	NA	264.0	9.5
2-26	900	15	NA	269.1	9.0
2-5	925	3	263.5	267.2	9.0
2-12	925	3	265.7	269.2	9.0
2-13	925	3	259.7	267.7	10.0
2-28	925	8	NA	266.5	7.5
2-29	925	15	NA	266.5	9.0
2-30	950	3	NA	269.0	8.0
2-17	950	8	NA	261.6	10.0
2-31	950	8	NA	263.5	8.5
2-32	1000	1	NA	255.0	9.0
2-18	1000	3	NA	252.4	9.5
2-33	1000	3	NA	255.0	10.0
2-19	1000	8	NA	242.9	12.0

NOTES:

1. All results obtained with 0.505-in. diameter specimens
2. Not available
3. All specimens longitudinal

APPENDIX III - TENSILE DATA SUMMARY

UNIAXIAL TENSILE DATA - HEAT A PARENT PLATE MARAGED AT 875°F

SPEC. NO.	TIME AT TEMPERATURE (HOURS)	SPECIMEN ORIENTATION	0.2% YIELD STRESS (ksi)	ULTIMATE STRESS (ksi)	% ELONG. (IN 2" GAGE)	%RED. IN AREA
AP21	1	L	240.4	248.8	10.5	47.4
AP22	1	L	238.6	246.5	11.0	48.2
AP225	1	T	236.8	245.5	10.0	39.6
AP226	1	T	234.8	240.0	9.5	40.1
AP23	3	L	250.1	260.9	11.0	44.3
AP24	3	L	254.2	259.9	12.0	51.1
AP227	3	T	248.6	258.3	9.5	40.7
AP228	3	T	250.4	259.8	8.0	36.6
AP25	6	L	254.7	263.4	9.0	43.5
AP26	6	L	259.1	265.7	10.0	39.5
AP229	6	T	249.4	264.7	7.0	35.7
AP230	6	T	255.3	265.3	6.5	36.7
AP27	12	L	265.4	271.5	8.0	37.6
AP28	12	L	264.5	272.5	8.0	37.7
AP231	12	T	264.9	272.0	8.0	32.8
AP232	12	T	261.9	270.7	8.0	29.8

1. L = Longitudinal
   T = Transverse

2. All results obtained with 0.505-in. diameter specimens.

APPENDIX III, Con't. - TENSILE DATA SUMMARY

UNIAXIAL TENSILE DATA - HEAT A PARENT PLATE
MARAGED AT 900°F

SPEC. NO.	TIME AT TEMPERATURE (HOURS)	SPECIMEN ORIENTATION	0.2% YIELD STRESS (ksi)	ULTIMATE STRESS (ksi)	% ELONG. (in 2")	%RED. IN AREA
AP29	1	L	243.2	249.9	10.0	45.2
AP210	1	L	240.0	249.9	10.0	45.5
AP233	1	T	239.2	249.9	8.0	34.0
AP234	1	T	242.3	250.6	9.0	36.6
AP211	3	L	255.2	261.6	10.5	42.2
AP212	3	L	255.0	261.6	8.0	37.6
AP235	3	T	252.2	262.9	8.0	32.7
AP236	3	T	256.0	261.8	7.0	32.0
AP213	6	L	260.3	265.7	9.0	39.1
AP214	6	L	259.8	265.4	10.0	42.8
AP237	6	T	260.8	267.4	8.0	34.4
AP238	6	T	259.1	267.0	8.0	35.3
AP215	12	L	261.8	268.2	10.0	43.5
AP216	12	L	259.8	266.4	9.0	39.0
AP239	12	T	260.9	268.5	6.5	34.4
AP240	12	T	261.9	268.4	7.0	3[illegible]0

NOTES:

1. L = Longitudinal
   T = Transverse

2. All results obtained with 0.505-in. diameter specimens.

APPENDIX III, (Cont'd) - TENSILE DATA

UNAXIAL TENSILE DATA HEAT A PARENT PLATE MARAGED AT 950°F

SPEC. NO.	TIME AT TEMPERATURE (HOURS)	SPECIMEN ORIENTATION	0.2% YIELD STRESS (KSI)	ULTIMATE STRESS (KSI)	% ELONG. (IN 2")	% RED. IN AREA
AP217	1	L	247.8	255.5	10.0	42.2
AP218	1	L	248.3	254.7	10.0	49.6
AP241	1	T	247.6	254.5	9.0	39.0
AP242	1	T	247.0	254.6	8.0	39.0
AP219	3	L	251.7	260.1	11.0	48.1
AP220	3	L	250.6	260.4	10.0	44.2
AP243	3	T	254.2	261.3	10.0	38.7
AP244	3	T	254.7	261.6	7.0	36.6
AP221	6	L	250.6	256.3	10.0	39.2
AP222	6	L	247.8	256.3	11.5	44.7
AP245	6	T	251.7	259.8	10.0	35.7
AP246	6	T	252.7	259.6	10.0	35.7
AP223	12	L	239.9	247.6	12.0	37.4
AP224	12	L	240.7	248.1	13.0	50.9
AP247	12	T	243.5	252.4	10.5	39.1
AP248	12	T	241.9	251.2	10.5	41.1

1. L = Longitudinal

   T = Transverse

2. All results obtained with 0.505 in. diameter specimens.